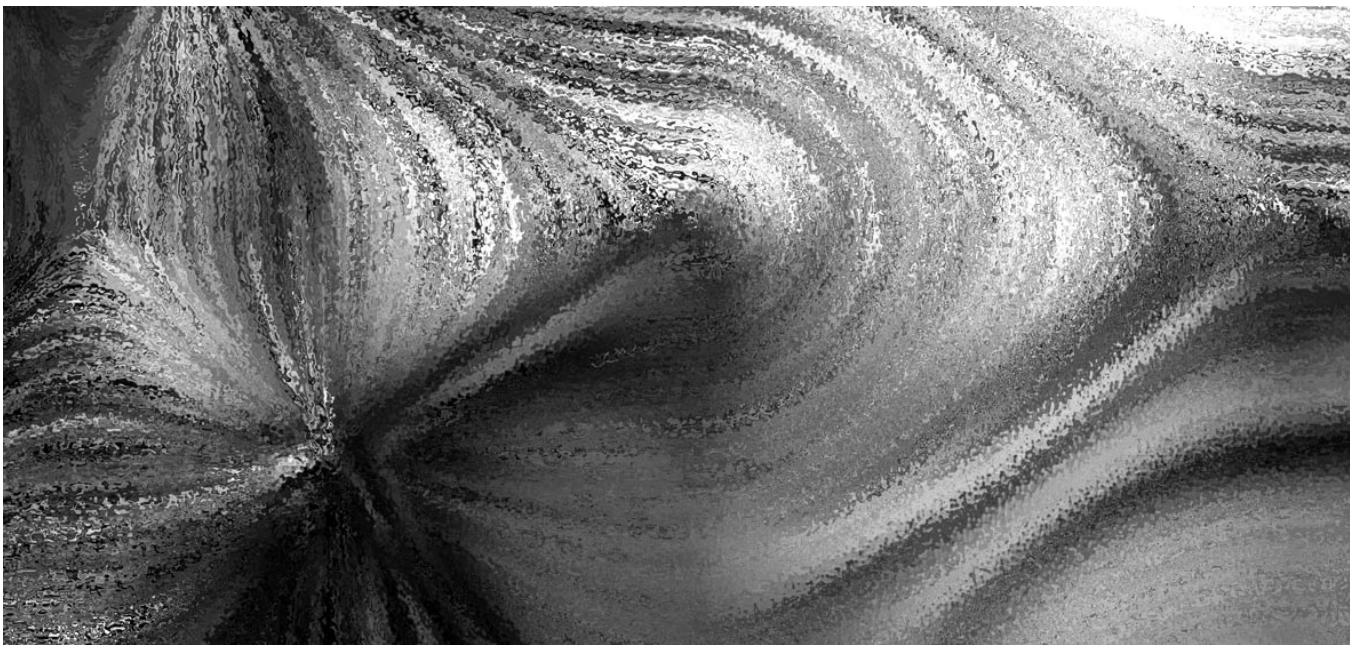
Mechanics & Sport Performance Assignments & Solutions



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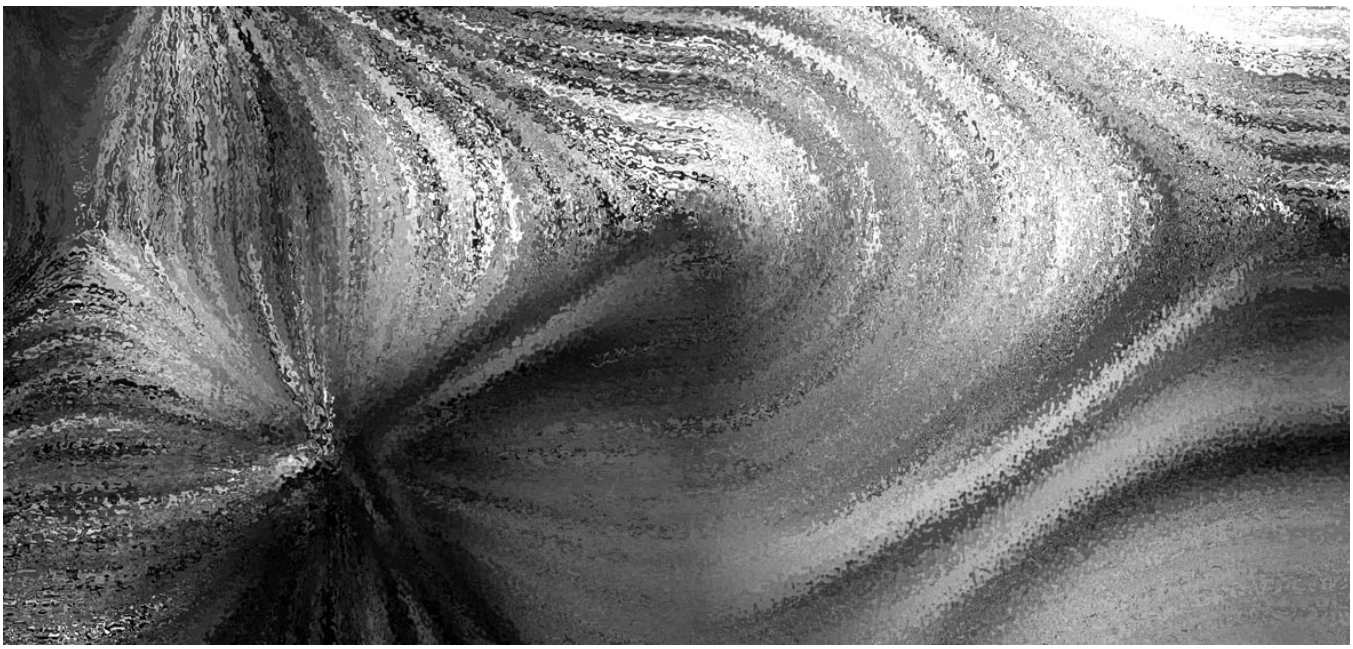
Introduction

The accompanying Assignments use a variety of approaches to investigate mechanical principles as they apply to sports performance. Most tasks may be undertaken by individuals and only one set of tasks require some additional equipment. The tasks mainly focus on investigations which require the processing and interpretation of data and information that has been provided, rather than factual recall.

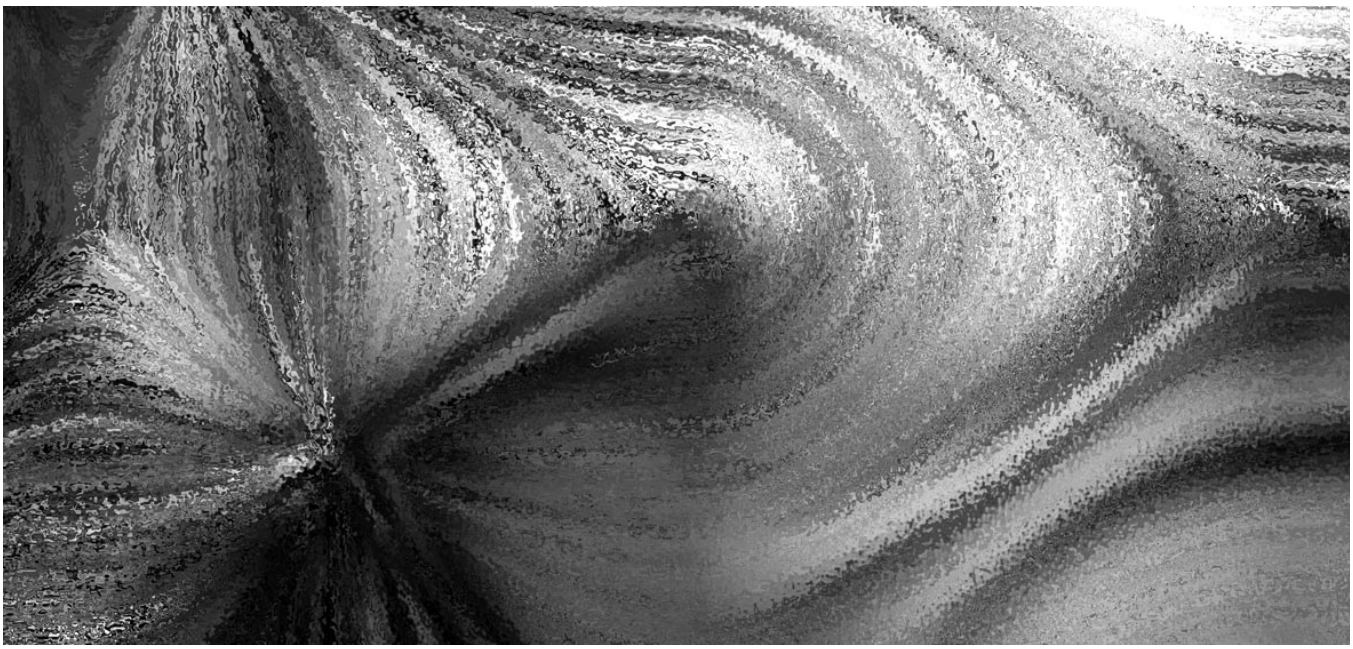
Where relevant, concepts are investigated using data and problems that relate directly to sports performers, and not just to sports implements, or non-sports related objects. Although many tasks require students to undertake numerical techniques to arrive at solutions or to facilitate interpretations of the data, the numerical skills required should be within the grasp of students without specialist mathematical knowledge. Where assignments involve repetition of basic numerical routines students may be encouraged to use information technology support (e.g. spreadsheets) to assist the calculation process.

As several Assignment sheets require the construction of graphical material, scaling factors in the graphical results shown in the solutions sheets may not always match those produced by students. In some cases processes involved in the production of the solution sheets may also have affected scaling information.

ASSIGNMENTS



ASSIGNMENT ONE
DISTANCE & DISPLACEMENT



DISTANCE AND DISPLACEMENT

These problems consider the difference between distance and displacement, and require some simple procedures for calculating characteristics of vector quantities to be used.

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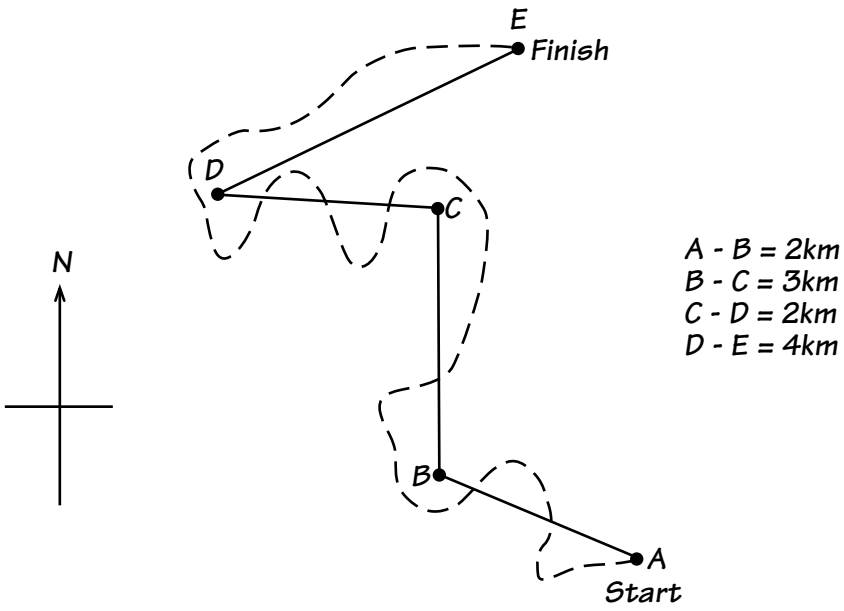
1 Answer

Figure 1 shows a representation of the course for a yachting race. The solid line represents the straight line path between the buoys that the boats are required to pass. The dotted line represents the 17 km path actually taken by the boat that won the race. Note that Figure 1 is not drawn to scale.

Figure 1 Diagram representing the course for a yachting race.



Draw a scale diagram of the above race.

Use a scale of 1 cm on your graph to represent 1 km of the race. The angle of each line is recorded below. Each angle should be measured from North in an anti-clockwise direction.

From A to B	70°
From B to C	0°
From C to D	90°
From D to E	300°

2 Answer

The distance the yacht travelled during the race was 17 km, what was the displacement it experienced from the start to the finish?

3 Answer

Using your diagram work out by direct measurement the following displacements experienced by the yacht:

a from A to C

b from B to D

c from A to D

d from C to E

e from B to E

4 Answer

By using Pythagoras's theorem calculate the magnitude value for the vector displacement from B to D (Solutions Figure S1).

5 Answer

By using trigonometry calculate the direction value for the vector displacement from B to D.

6 Solution not supplied

Compare the calculated results with those from your construction.

7 Answer

Using the directly measured values for the magnitude and direction of the displacement from A to E determined previously, work out how far the yacht travelled west.

8 Answer

Using the method described in 7 work out how far the yacht travelled north.

Table 1 Record of the vertical position of a point at the centre of a jumper's body (centre of gravity) taken at a series of 0.05 second intervals. The record is for the take off phase of a vertical jump.

Col 1 Time *(s)*	Col 2 Position *(m)*	Col 3 Displacement *(m)*
0.00	1.04	
0.05	1.03	
0.10	1.02	
0.15	1.01	
0.20	1.00	
0.25	0.98	
0.30	0.94	
0.35	0.88	
0.40	0.82	
0.45	0.78	
0.50	0.74	
0.55	0.72	
0.60	0.72	
0.65	0.75	
0.70	0.81	
0.75	0.92	
0.80	1.08	
0.85	1.14	

9 Answer

From observation of the data in Table 1, record the displacement experienced by the jumper at take off relative to his/her starting position.

10 Answer

Record the displacement of the point for each 0.05 s interval in Column 3 of Table 1.

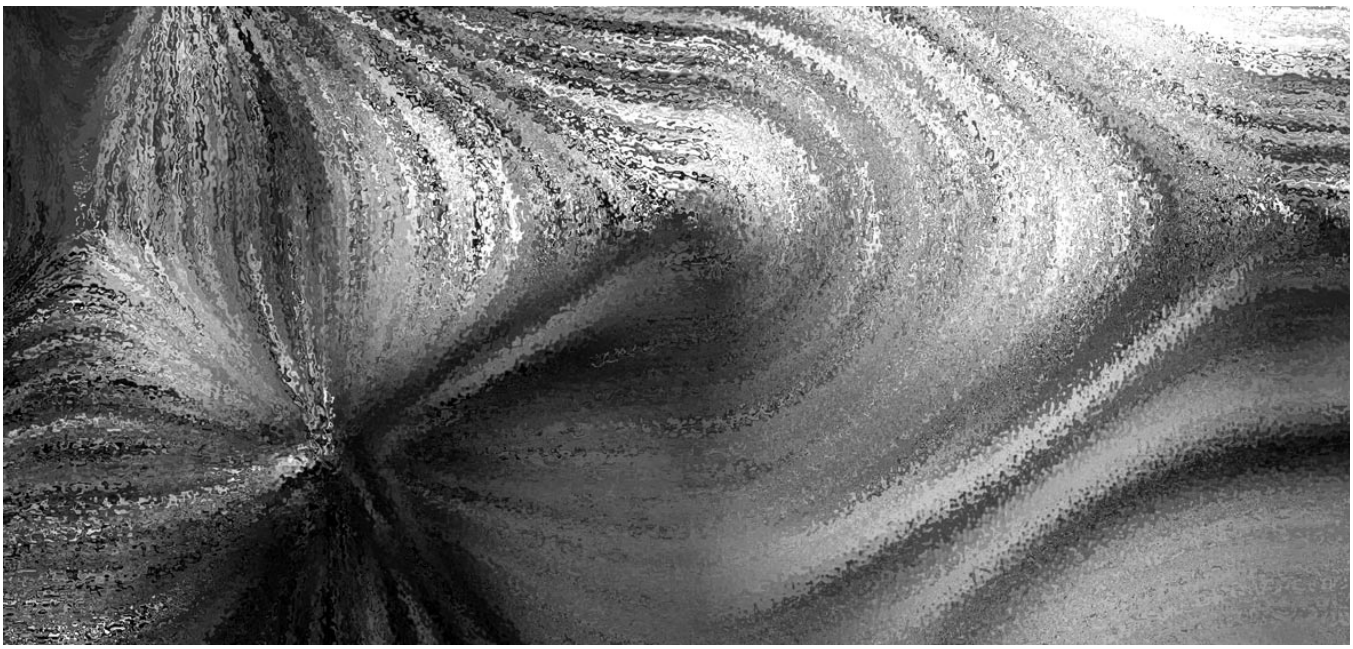
Use plus and minus signs to indicate the direction in which the point travelled during a time interval. Plus values should indicate movements in an upwards direction, and minus values should indicate movements in a downwards direction.

11 Answer

What was the total distance that the point moved from the start to take off?

ASSIGNMENT TWO

CALCULATING, GRAPHING & INTERPRETING POSITION, VELOCITY & ACCELERATION VALUES



CALCULATING, GRAPHING & INTERPRETING POSITION, VELOCITY & ACCELERATION VALUES

The following set of questions considers methods of describing and recording the changes in the horizontal motion of a sprinter who is taking part in a 100 m running race. The race is run along the straight of a running track from the start to the finish line with no changes in direction.

12 Answer

Using the data in Table 2 work out the time the runner took for each of the 10 m intervals, and record them in Column 3 of Table 2.

Table 2 Times recorded for a 100 m sprint at 10 m intervals.

Col 1 Position from Start *(m)*	Col 2 Cumulative Time *(s)*	Col 3 Time for 10 m Intervals *(s)*	Col 4 Average Velocity $(m \cdot s^{-1})$
0	0.00		
10	1.66		
20	2.84		
30	3.88		
40	5.00		
50	5.95		
60	6.97		
70	7.93		
80	8.97		
90	10.07		
100	11.19		

13 Answer

Using the formula:

$$\text{Average Velocity} = \frac{\text{Displacement}}{\text{Time}}$$

calculate the average velocity over each 10 m interval, and record them in Column 4 of Table 2.

On completing the calculation you should note that there are some variations in the average velocity results which would not be expected in a 100 m race. It would not be expected for the runner to get slower in the middle part of the race unless there was some exceptional circumstance. The reasons for these fluctuations are almost certainly related to the data collection process.When the original data was collected, it is highly likely that some errors due to factors such as incorrect timing and distance measurement were introduced. These errors may not be apparent when you collect the data, but soon become obvious as the data is processed. Because of this, when analysing sports events, the data frequently has to be 'smoothed'. The next stage in this task is to 'smooth' the data and then to recalculate the velocity values.

14 Answer

Draw a graph (using as large a scale as possible) of the original position data of the sprinter plotted against time (Solutions Figure S2).

Plot time values on the horizontal axis. When you have plotted the points, look carefully at your graph and draw a 'smooth' line which goes through or close to the points you have marked. The smoothness of the line you draw is the key to getting more representative data than in the first stage.

15 Answer

When you have drawn your graph, read data off the graph so that you can enter it into Table 3. Enter the position data in Column 2.

16 Answer

Enter the displacement in one second in Column 3 of table 3.

17 Answer

Calculate the average velocity for each time interval and enter in Column 4 of Table 3.

Note, that the table requires data in a format which has time as the basic unit rather than position (ie 10m intervals on the vertical axis in the first calculation, but one second intervals on the horizontal axis in the second calculation). By reworking the data in this way subsequent calculations will be much easier.

When showing the displacement values and average velocity values in Table 3 it is strongly recommended that these values be placed on a line which is between the limits of the time interval as shown in the table.

Table 3 Position from start, displacement, and average velocity of the sprinter in a 100 m sprint.

Col 1 Time *(s)*	Col 2 Position	Col 3 Displacement *(m)*	Col 4 Average Vel' *($m.s^{-1}$)*
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

18 Answer

Plot a velocity v time graph; scaling the axes of your graph appropriately (Solutions Figure S3).

Look carefully at your results. Note, that when you draw your graph, you should plot the average velocity values at the mid point of a time interval. e.g. 0.5, 1.5, 2.5 etc. When the points have been plotted join them up with a continuous smooth line.

19 Answer

Look at the velocity v time graph you have drawn.

If you observe what you consider to be significant variations from gradually changing velocities, redraw the graph using a 'smooth line' (Solutions Figure S4).

Follow the guidelines for smoothing outlined previously .

The smoothing processes carried out on the data should give a better representation of what actually happened during the run in terms of the runners velocity. Once the graph is drawn it is possible to read off a velocity value for any particular time value. However, it is important to realise that the line you draw can only give you an estimate of velocity values for any particular point in time.

20 Solution not supplied

In principle to get a better estimate of instantaneous velocity values, the tangent construction method may be used. Follow the procedures outlined below using your 'smoothed' graph, which records the runner's position with respect to time.

To calculate the instantanteous velocity at two seconds, first draw a vertical line from the two second value on the horizontal axis until it intersects with the curve. At the point of intersection draw a tangent to the curve. Using the tangent as the hypoteneuse construct a right angled triangle. To ease calculation, make the side of the right angled triangle that is parallel to the time axis a whole unit length e.g. 1 s, 2 s or 3 s, etc.

Calculate the gradient of the tangent by dividing the displacement represented by the vertical side of the triangle, by the time represented on the horizontal side of the triangle.

21 Solution not supplied

How does this instantaneous value compare with the value that you can obtain from your original velocity v time graph?

22 Answer

What are the problems of using the tangent method?

23 Answer

Continue the process of differentiation (i.e. working out the differences between known values), that was used to calculate the average velocity to determine the average acceleration values.

Table 4 identifies the stages that you need to undertake to arrive at average acceleration values.

Start by reading off the estimated velocity values at each one second interval from your velocity v time graph and enter them in column 2 of Table 4.

24 Answer

Continue by calculating the changes in velocity and entering them in column 3 of Table 4.

25 Answer

Calculate the average accelerations, and enter them into column 4 of Table 4.

It is again recommended that you record the change in velocity values and average acceleration values in Table 4 on a line which is between the limits of the time interval.

Table 4 Stages needed to arrive at average acceleration values.

Col 1 Time (s)	Col 2 Velocity ($m \cdot s^{-1}$)	Col 3 Change in Velocity ($m \cdot s^{-1}$)	Col 4 Average Acceleration ($m \cdot s^{-2}$)
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

When you complete the calculations it is highly likely that the acceleration results will be somewhat variable. The reason for this is that, although you have smoothed the data, there will still be some errors. The process of differentiation always magnifies these errors, and in general it is difficult to get accurate acceleration information from data of this nature.

It is important to note that it is perfectly possible to calculate average acceleration values given only the original position and time values. If this were done then the format of the calculation table would be as shown in **Table 5**. Consideration of the table shows that the procedure leads to a reduction of information in terms of what is known about the beginning and end of the original set of data.

Table 5 Acceleration values calculated from original position and time values.

Col 1 Time	Col 2 Position	Col 3 Displacement	Col 4 Average Vel'	Col 5 Change in Vel'	Col 6 Average Accel'
★	★				
		★	★		
★	★			★	★
		★	★		
★	★				

★ = numerical value

26 Answer **Plot a graph of acceleration v time from the data in Table 4 (Solutions Figure S5).**

27 Answer

Using the data in Table 6, and the same techniques as described before, plot position v time, and then velocity v time information for the runner (Solutions Figures S6 and S7).

Table 6 Data of race between runner and cyclist over 100 m. The linear motion of a runner and cyclist in a race over a straight line 100 m distance with no change in direction was recorded on video tape fitted with a timer (Watkins 1983).

Col 1 Position from start *(m)*	Col 2 Runner's Time *(s)*	Col 3 Cyclist's Time *(s)*
0	0	0
10	1.84	2.40
20	3.24	4.04
30	4.48	5.40
40	5.60	6.56
50	6.84	7.68
60	7.96	8.78
70	9.16	9.84
80	10.36	10.80
90	11.56	11.76
100	12.76	12.54

28 Solution not supplied

Repeat the procedures to plot position v time; and then velocity v time information for the cyclist.

29 Solution not supplied

With reference to the graphical data discuss similarities and differences in the velocity values calculated for the sprinter and cyclist in the beginning, middle and end phases of the race.

30 Answer

Using the data in Table 7, and the procedures explained in the book for the numerical calculation of velocity, calculate for each athlete average velocity values for each 10 m interval. Plot each athlete's velocity v time trace on the same graph (Solutions Figure S8). You can assume the atheletes ran in a straight line with no change in direction.

Table 7 Data from IAAF Biomechanical Analysis Programme - 1988 Seoul Olympics 100 metres Finals.

Col 1 Position from start *(m)*	Col 2 B Johnson *(s)*	Col 3 C Lewis *(s)*	Col 4 Ms. F G Joyner *(s)*
0	0.00	0.00	0.00
10	1.83	1.89	2.00
20	2.87	2.96	3.09
30	3.80	3.90	4.09
40	4.66	4.79	5.06
50	5.50	5.65	5.97
60	6.33	6.48	6.89
70	7.17	7.33	7.80
80	8.02	8.18	8.71
90	8.89	9.04	9.62
100	9.79	9.92	10.54

Data from Inglis R.(1989) Training for Acceleration. Athletics Coach V 23 No 1.

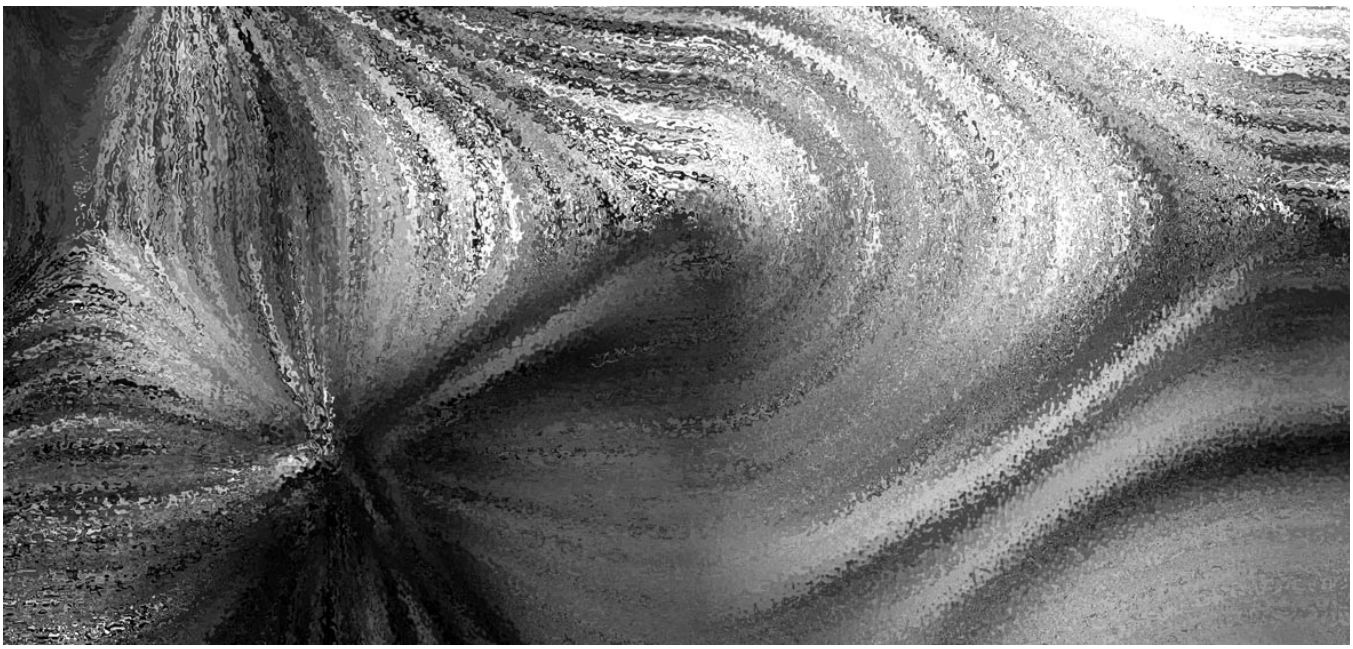
31 Solution not supplied

Using the information from your graph compare the velocity of the runners in the beginning, middle and end phases of the race.

32 Answer

What characteristics of the velocity v time trace provides the information about the magnitude of the acceleration of the runner during the race?

ASSIGNMENT THREE
SPORT RELATED COMPONENT & RESULTANT VECTOR QUESTIONS



SPORT RELATED COMPONENT & RESULTANT VECTORS

For the questions outlined below use numerical techniques, i.e. Pythagoras's theorem and trigonometrical methods, to calculate the required component and resultant vectors.

Answers

33 **If a high jumper takes off with a speed of 5.5 $m \cdot s^{-1}$, and at an angle of 78° to the ground, calculate the vertical and horizontal component velocities at take-off.**

34 **If a basketball player releases a set shot with a speed of 18 $m \cdot s^{-1}$, at an angle of 70° to the ground, calculate the vertical and horizontal component velocities at the release of the ball.**

35 **If a rugby ball is punted down field with a speed on leaving the players foot of 30 $m \cdot s^{-1}$, and at an angle of 38° to the ground, calculate the horizontal and vertical component velocities of the ball as it leaves the players foot.**

36 **If a shot is known to have a vertical component velocity of 10 $m \cdot s^{-1}$, and a horizontal component velocity of 12 $m \cdot s^{-1}$ at release, calculate its resultant release velocity (that is the speed and angle of release).**

37 **If a long jumper is known to have a vertical velocity at take off of 2.9 $m \cdot s^{-1}$, and a horizontal velocity of 9.0 $m \cdot s^{-1}$, calculate the resultant velocity of the jumper at take off, that is the speed and angle of take off.**

38 **If a javelin thrower is recorded as releasing the javelin at a speed of 30 $m \cdot s^{-1}$, and an angle of 41° to the ground, calculate the horizontal and vertical component velocities at release.**

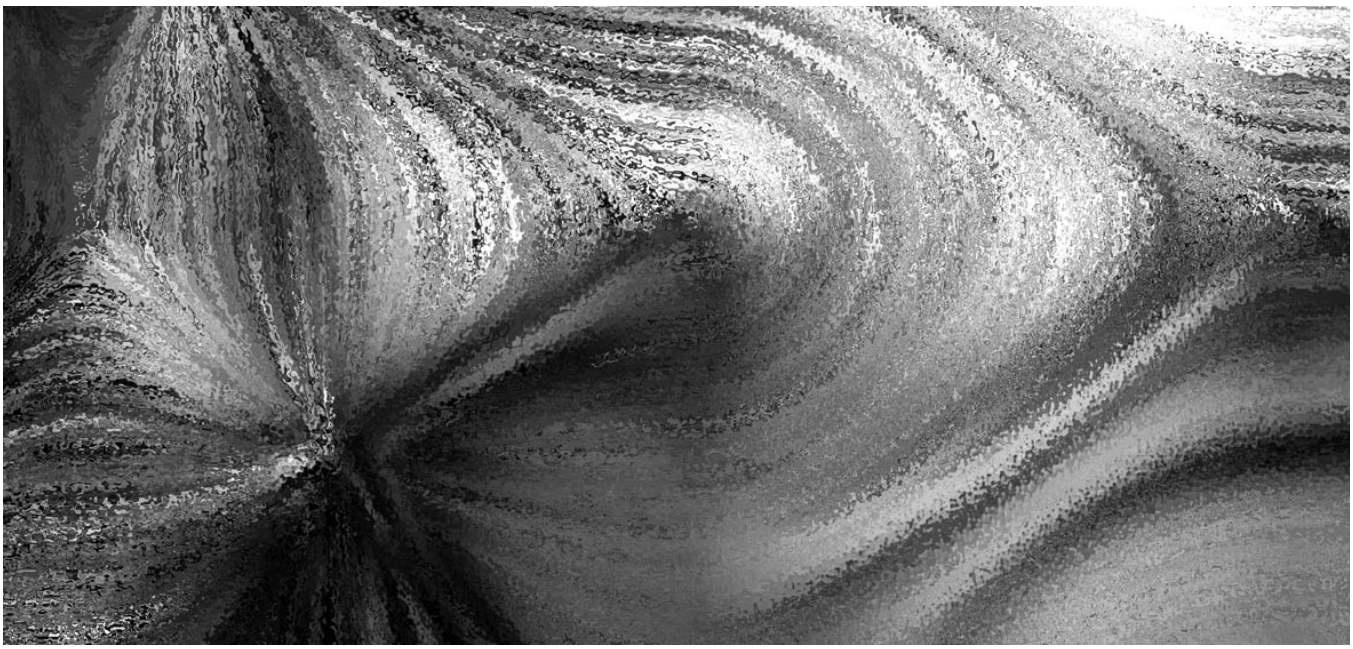
39 **If the velocity components of a long jumper's take off are known to be 7.0 $m \cdot s^{-1}$ horizontally, and 2.5 $m \cdot s^{-1}$ vertically, calculate the resultant velocity of the jumper (that is speed and angle of take off).**

Answers

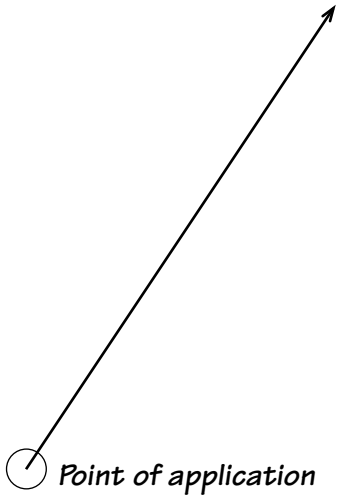
40 **If a high jumper has a take off speed of 4.2 $m \cdot s^{-1}$, and leaves the ground at an angle of 70° to the horizontal, what was the jumper's vertical and horizontal velocities at take off?**

41 **If a cricketer throws a ball in from the boundary with a speed of 35 $m \cdot s^{-1}$, and at an angle of 45° to the ground, what were the vertical and horizontal component velocities at release?**

ASSIGNMENT FOUR
VECTORS & SPORT



VECTORS & SPORT

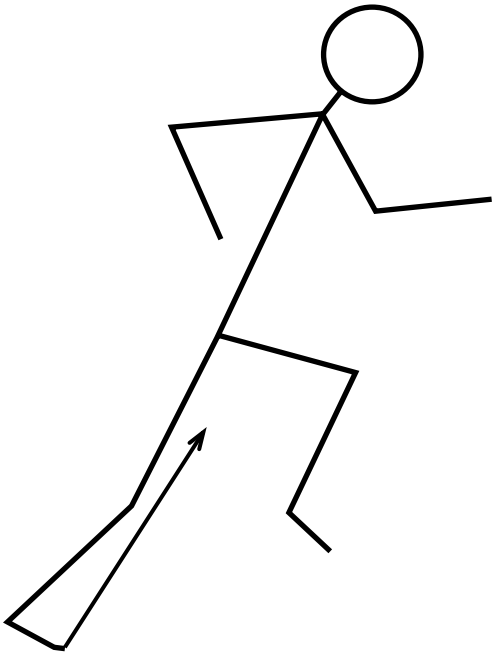


The investigation explained in this Assignment looks at the concept of vectors within the context of a sport science experiment analysing foot contact during running. A vector quantity has both magnitude and direction and this can be represented by using an arrow. This investigation utilises another feature of vector representation, in addition to magnitude and direction, which is known as the point of application. In terms of the arrow representation of a vector quantity, you can think of this as the point where you would draw the base of the arrow as shown in **Figure 2**.

Figure 2 Point of application of a vector.

A sports biomechanician investigating running, will sometimes use a piece of equipment called a force platform, which measures the forces that are exerted on the ground during running. As a runner makes contact with the ground, s/he applies a force to the ground, and in return experiences an equal and opposite ground reaction force (Newton's Third Law). At a particular point in time during the contact phase this could be represented as a force acting on the runner as shown in Figure 3.

Figure 3 Ground reaction force acting on a runner at an instant in time during contact with the ground.



The point from which the ground reaction force is drawn is the point of application of the vector representing the ground reaction force. It should however be noted that, during the time that the foot is in contact with the ground, the force is being applied to an area of the ground. Similarly, the corresponding ground reaction is applied as a force to the area of the foot/shoe that is in contact at that particular moment. Where force is being applied over an area (rather than at a point) we talk about pressure.

The question now arises as to which point should be selected as the point of application of the ground reaction force vector when it is to represent a pressure.

Frequently, when drawing diagrams such as Figure 3, there is no special point selected, as long as the force is shown as acting within the overall dimensions of contact area. However, sometimes it is necessary to be more accurate than this. In these cases an averaging procedure is used to represent the pressures that are present at a particular moment as acting at a point. This point is called the Centre of Pressure.

Force platforms can provide information about the centre of pressure for a discrete number of points during a foot contact, and will give some idea of where the main areas of pressure are on a running shoe/foot at the selected times during contact.

The two tasks that follow are related. The first task investigates the centre of pressure at a number of points throughout the contact phase for three different runners. The second task combines the centre of pressure data with the magnitude and direction elements of ground reaction force vectors, and represents the information in a vectorgram.

Biomechanics research which has looked at running styles has sometimes categorised runners according to the kind of foot strike they make with the ground. Typically the runners are put into one of three categories: **rear-foot** strikers, **mid-foot** strikers and **fore-foot** strikers.The criterion used to decide which category a runner falls into, is the position of the centre of pressure at first contact with the ground. If the centre of pressure first occurs in the rear third of the shoe outline the runner is defined as a rear-foot striker, if in the middle third as a mid-foot striker, and if in the front third as a fore-foot striker.

Using the foot outline for athletes **P**, **Q** and **R** and the centre of pressure coordinates for the corresponding athletes from **Tables 8, 9 and 10,** the task investigates the foot strike characteristics of the athletes. Note that all three athletes wore the same make of shoe and had the same shoe size so the shoe outline provided may be used for all three athletes. Also note that the data provided for each subject in each case refers to a single left foot contact.

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42 Answer

Trace a copy of the shoe outline (Figure 4) onto tracing paper or thin paper through which the grid of graph paper can be seen.

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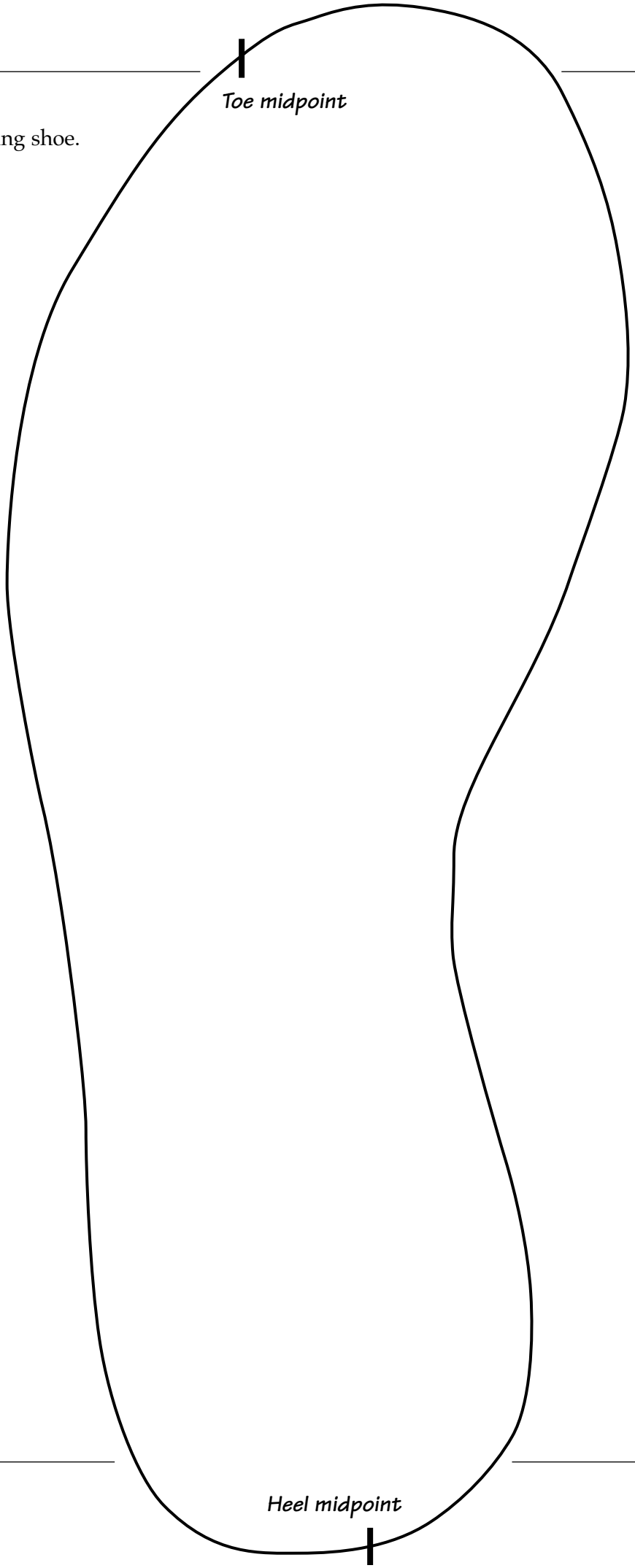
43 Answer

On the copy of the shoe outline draw the line down the middle of the shoe which extends from the heel to the toe; mark on the midline, one point which is at 70% of the shoe's length, and a second point which is at 90% of the shoe's length. In both cases the distance should be measured from the point where the midline intersects the heel of the outline. In addition draw two lines perpendicularly (to the mid line) across the shoe such that the shoe length is divided into thirds (Solutions Figure S9).

Figure 4
Outline of a running shoe.



44 Answer

Table 8 gives the x and y co-ordinates (Ax, Ay) for the centre of pressure of a left footfall for subject P with, the origin placed at the centre of the force platform. Observing the range of values for Ax and Ay (the centre of pressure coordinates)

Plot a graph which represents the path followed by the centre of pressure.

(A3 graph paper is preferable for an easier fit of the origins of the axes, which can be situated roughly in the middle of the sheet). Use a 1mm = 1mm scale on both the x and y axes.

Table 8 Force and Centre of Pressure data for Subject P

Col 1 Time *(s)*	Col 2 Fz *(N)*	Col 3 Fy *(N)*	Col 4 Ax *(mm)*	Col 5 Ay *(mm)*
0.0000	561	– 9	– 53	– 53
0.0080	1237	– 103	– 51	– 28
0.0160	1579	– 180	– 51	– 21
0.0240	1210	– 204	– 51	– 10
0.0320	1003	– 220	– 50	2
0.0400	1113	– 232	– 50	7
0.0480	1311	– 290	– 50	22
0.0560	1401	– 253	– 50	32
0.0640	1530	– 182	– 50	46
0.0720	1706	– 166	– 50	49
0.0800	1755	– 133	– 49	59
0.0880	1755	– 112	– 49	67
0.0960	1735	– 88	– 50	76
0.1040	1735	– 71	– 49	83
0.1120	1701	– 35	– 49	91
0.1200	1657	4	– 50	99
0.1280	1613	38	– 51	106
0.1360	1562	65	– 51	114
0.1440	1491	99	– 51	121
0.1520	1403	141	– 51	129
0.1600	1318	172	– 50	136
0.1680	1228	197	– 50	142
0.1760	1123	222	– 50	150
0.1840	1005	241	– 50	157
0.1920	886	250	– 49	163
0.2000	754	240	– 48	170
0.2080	612	200	– 46	179

Note: Data shown sampled at 125 Hz. (Original data set sampled at 500 Hz). Data shown truncated at beginning and end due to potential averaging errrors resulting from the recording instrumentation.

45 Answer

Mark on the graph the coordinates of the 70% and 90% points of shoe length as indicated in Table 9.

Table 9 70% and 90% Shoe length coordinates

	70% x,y(mm)	90% x,y(mm)
Subject P	– 49,110	– 49,165
Subject Q	0,103	3,157
Subject R	– 44,37	– 49,92

46 Answer

Overlay the traced shoe outline obtained in 47 on to the graph paper such that the 70% and 90% points on the traced outline match up with the 70% and 90% marked on the graph paper. Draw around the outline so that the foot shape appears on the graph paper (Solution Figure S10).

47 Answer

Using the traced outline and the criterion identified at the start of the task determine whether the runner would be classed as a front foot, mid foot or rear foot striker.

48 Answer

Using the data in Tables 9 and 10 follow the same procedures and determine the foot strike characteristics for Subject Q (Solution Figure S11).

49 Answer

Using the data in Tables 9 and 11 follow the same procedures and determine the foot strike characteristics for Subject R (Solution Figure S12).

50 Answer

This next task aims to integrate centre of pressure and ground reaction force information, to provide a visual representation of ground reaction force vectors acting during a running footfall. The force conventions used are such that horizontal ground reaction forces that are positive should be considered as acting on the runner in the direction of the the run, and negative forces as acting on the runner in the opposite direction of the run. You will need to use the data in Table 8.

Using standard graph paper draw an axis across the bottom of the paper, scale and label the axis so that they coordinates of the centre of pressure can be located on the axis (Solutions Figure S13). Mark clearly on this axis they co-ordinates of the centre of pressure .

In the next stage, each of the Ay coordinate positions on the axis is going to be taken as an origin for a new graph. This will involve drawing a graph where the horizontal axis is superimposed on your existing axis, and therefore you will need to be careful about the way you draw these lines. The vertical axes that you draw will need to be drawn in pencil and very faintly.

51 Answer

Select the first centre of pressure Ay coordinate on your original axis and treating this as an origin draw a set of vertical and horizontal axes. These axes are to be used to plot the resultant of the horizontal and vertical ground reaction forces that were acting at the same time that the centre of pressure was recorded. The axis that you draw should therefore accommodate the vertical force value, and the x axis the horizontal force value that is associated with the first centre of pressure point as displayed in Table 8 for Subject P. The scales used on the vertical and horizontal axes should be the same.

Take the horizontal and vertical force values for position 1 and plot a single point on your graph which represents these co-ordinates. Draw a line from the origin (the first centre of pressure point) to the new point just plotted, and place an arrow head at the top of the line so that it coincides with the plotted point (Solutions Figure S14).

This arrow now represents the resultant ground reaction force vector, that was acting on the runner at the time the first centre of pressure value was recorded.

52 Answer

Repeat the procedures outlined for each of the centre of pressure points that you plotted on the original axes. (Solution Figure S15).

You may wish to number the ground reaction force vectors so that the time order can be seen even if the vector arrows overlap.

Once the resultant force vector arrows have been drawn, it is a good idea to erase the vertical and horizontal axes that you used to calculate their positions, as this will give a clearer picture of the pattern that the force vectors are making.

Your vectorgram (final diagram) when completed will show the point of application, magnitude and direction attributes of the ground reaction force vectors for a series of points during a foot contact. It is important to appreciate that each vector only shows what is happening at a particular instant in time.

53 Answer

By looking at the vectorgram decide how the ground reaction force is affecting the runner's horizontal acceleration during the foot contact.

54 Answer

Note that a simplified vectorgram can be constructed with the centre of pressure data omitted. In this case all vectors are drawn with a common point of application (Solutions Figure S16).

55 Answer

Using the data in Table 10 for subject Q, construct the associated vectorgram.

Table 10 Force and Centre of Pressure data for Subject Q

Col 1 Time *(s)*	Col 2 Fz *(N)*	Col 3 Fy *(N)*	Col 4 Ax *(mm)*	Col 5 Ay *(mm)*
0.0000	205	– 80	– 46	60
0.0080	502	– 152	– 37	72
0.0160	893	– 241	– 28	66
0.0240	1396	– 275	– 22	60
0.0320	1588	– 263	– 16	55
0.0400	1597	– 249	– 11	53
0.0480	1681	– 140	– 9	56
0.0560	1570	– 104	– 8	61
0.0640	1463	– 119	– 7	67
0.0720	1513	– 113	– 7	72
0.0800	1559	– 109	– 7	77
0.0880	1604	– 107	– 7	83
0.0960	1635	– 89	– 7	88
0.1040	1652	– 67	– 6	93
0.1120	1665	– 35	– 6	96
0.1200	1649	10	– 6	101
0.1280	1623	41	– 5	106
0.1360	1605	55	– 4	112
0.1440	1579	90	– 3	119
0.1520	1518	132	– 1	126
0.1600	1486	179	1	131
0.1680	1216	236	3	136
0.1760	1059	292	5	142
0.1840	878	249	7	149
0.1920	642	218	12	156

Note: Data shown sampled at 125 Hz. (Original data set sampled at 500 Hz). Data shown truncated at beginning and end due to potential averaging errors.

56 Answer

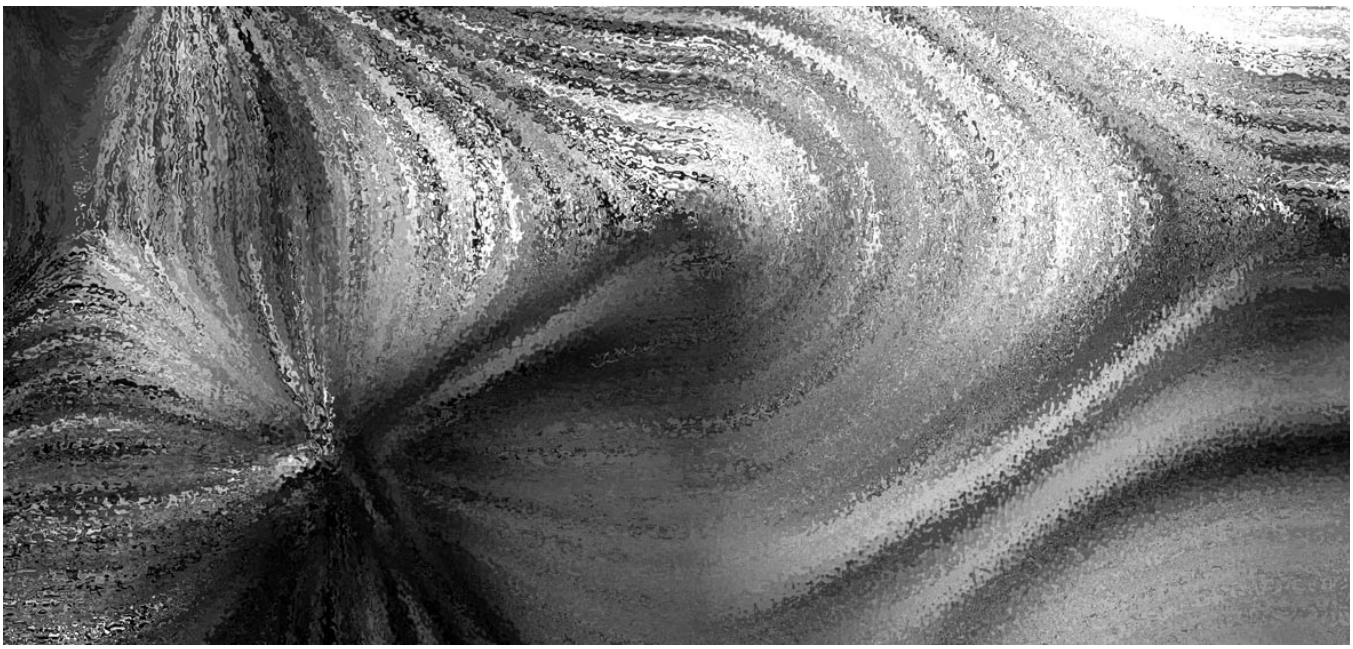
Using the data in Table 11 for subject R, construct the associated vectorgram.

Table 11 Force and Centre of Pressure data for Subject R

Col 1 Time *(s)*	Col 2 Fz *(N)*	Col 3 Fy *(N)*	Col 4 Ax *(mm)*	Col 5 Ay *(mm)*
0.0000	321	– 119	– 60	78
0.0080	476	– 162	– 48	92
0.0160	747	– 216	– 49	72
0.0240	815	– 247	– 50	61
0.0320	1150	– 246	– 51	51
0.0400	1323	– 218	– 52	44
0.0480	1447	– 207	– 52	33
0.0560	1475	– 189	– 53	25
0.0640	1418	– 151	– 54	19
0.0720	1342	– 133	– 54	13
0.0800	1298	– 109	– 53	8
0.0880	1262	– 92	– 53	3
0.0960	1208	– 57	– 53	– 3
0.1040	1178	– 53	– 52	– 8
0.1120	1103	– 40	– 52	– 13
0.1200	1052	– 29	– 44	– 8
0.1280	1011	– 9	– 40	0
0.1360	1048	10	– 39	7
0.1440	1183	47	– 38	14
0.1520	1286	61	– 38	21
0.1600	1404	116	– 37	29
0.1680	1492	148	– 37	38
0.1760	1573	217	– 37	45
0.1840	1481	238	– 36	52
0.1920	1211	255	– 35	59
0.2000	1018	229	– 34	67
0.2080	726	200	– 32	78
0.2160	448	147	– 30	90

Note: Data shown sampled at 125 Hz. (Original data set sampled at 500 Hz). Data shown truncated at beginning and end due to potential averaging errors.

ASSIGNMENT FIVE
IMPULSE



IMPULSE

The focus of this set of questions is on the concept of impulse.

57 Answer

Identify each variable in the equation:

$F \times t = (m \times vf) - (m \times v_i)$

58 Answer

With reference to the variables in the equation, explain the concepts of impulse and momentum and the relationship between them.

59 Answer

If a stationary soccer ball of fixed mass 2 kg has a constant force of magnitude 100 Newtons applied to it for 0.4 seconds, how fast was the ball travelling at the end of this time period?

60 Answer

If a 70 kg high jumper spends 0.63 seconds in the air during a jump, and it is known that his/her downward vertical velocity was – 3.3 $m \cdot s^{-1}$ on landing, what was the jumper's vertical velocity at take off?

(Assume that the magnitude of the acceleration due to gravity is 9.8 $m \cdot s^{-2}$, and that 'up', is taken to be the positive direction).

61 Answer

Col 1 Time (s)	Col 2 Force (N)
0.00	769
0.02	761
0.04	756
0.06	737
0.08	708
0.10	688
0.12	666
0.14	637
0.16	590
0.18	561
0.20	539
0.22	515
0.24	541
0.26	527
0.28	561
0.30	588
0.32	593
0.34	639
0.36	625
0.38	629
0.40	678
0.42	681
0.44	690
0.46	700
0.48	744
0.50	805
0.52	876
0.54	1022
0.56	1193
0.58	1372
0.60	1562
0.62	1696
0.64	1752
0.66	1750
0.68	1728
0.70	1701
0.72	1679
0.74	1665
0.76	1662
0.78	1645
0.80	1638
0.82	1547
0.84	1315
0.86	693
0.88	0

Table 12 Vertical ground reaction force values, and corresponding time values for a number of sampled points during the take off phase of a vertical jump.

The data in **Table 12** show the vertical ground reaction force values, and the corresponding time values, for a number of sampled points during the take off phase of a vertical jump. The jumper had a mass of 78.5 kg, and used a technique which involved a downward counter movement, prior to the extension of the knee joint. The jump was initiated from a stationary starting position. Air resistance is assumed to be negligible and acceleration due to gravity as 9.8 $m{\cdot}s^{-2}$.

Plot a graph of vertical ground reaction force v time with the values provided in Table 12 (Solutions Figure S17).

Plot the force values on the vertical axis and plot the time values on the horizontal axis. Use centimetre square graph paper and scale the vertical axis at one cm equals 100 N and the horizontal axis at one cm equals 0.04 second. Label the axes appropriately and title the graph.

62 Answer

The area under the graph represents the impulse generated by the ground reaction force, and therefore can be calculated. The best way, without using complicated mathematics, is to estimate how many unit squares (1cm × 1cm on the graph paper) there are in the desired area. Start by shading all the complete squares within the area and record the result. Look at the remaining unshaded area and combine part squares with other part squares. Do this, one unit square at a time, shading the area when you have made your decision. Repeat this until all the area under the curve, from the start of the jump to the end of the jump, is completely shaded. Total the number of unit squares you estimate for the area.

Because the scale used in the graph was 100 N per cm on the vertical axis, and 0.04 s per cm on the horizontal axis, the impulse represented by one unit square is equal to 100 N × 0.04 s, which is 4 N·s. As one unit square on the graph paper represents a vertical ground reaction force impulse of 4 N·s, simply multiplying this by the number of unit squares that have been estimated to be under the curve, gives the total impulse generated by the ground reaction force during take off. Using this method:

Using this method, Calculate the total impulse generated by the ground reaction force during take off.

63 Answer

The gravitational force (the jumper's weight) will be constant throughout the period of time of the take off. Therefore the impulse due to gravity during the jump will simply be the weight of the jumper multiplied by the time it takes to undertake the take off. Note that as the force is acting in a downwards direction the impulse can be regarded as negative.

Calculate the impulse due to gravity.

64 Answer

By combining the ground reaction force impulse and the gravitational impulse (remembering that the latter is a negative value): calculate the net impulse acting on the jumper.

65 Answer

By rearranging the standard impulse momentum equation, where the mass of an object is known and remains constant, the change in velocity experienced by the jumper as a result of the net impulse can be determined.

Look carefully at the formula:

$$\frac{F \times t}{m} = vf - v_i$$

$F \times t$ = **Impulse**
m = **mass**
v_f = **Final velocity**
v_i = **Initial velocity**

and by substituting known values: calculate the velocity of the take off of the jumper.

(Remember that at the start of the jump the vertical velocity of the jumper was zero)

66 Answer

Col 1 Time (s)	Col 2 Force (N)
0.00	769
0.02	783
0.04	786
0.06	808
0.08	861
0.10	942
0.12	1013
0.14	1062
0.16	1076
0.18	1115
0.20	1220
0.22	1396
0.24	1530
0.26	1625
0.28	1691
0.30	1743
0.32	1716
0.34	1560
0.36	1298
0.38	886
0.40	190
0.42	0

Table 13 Vertical ground reaction force values of sampled points during the take off phase of a vertical jump without a counter movement.

Repeat the procedures for the set of data in Table 13 (Solutions Figure S18).

This data represents the same jumper undertaking a vertical jump but without a counter movement. That is, the jumper starts in a stationary position but with knees already flexed.

67

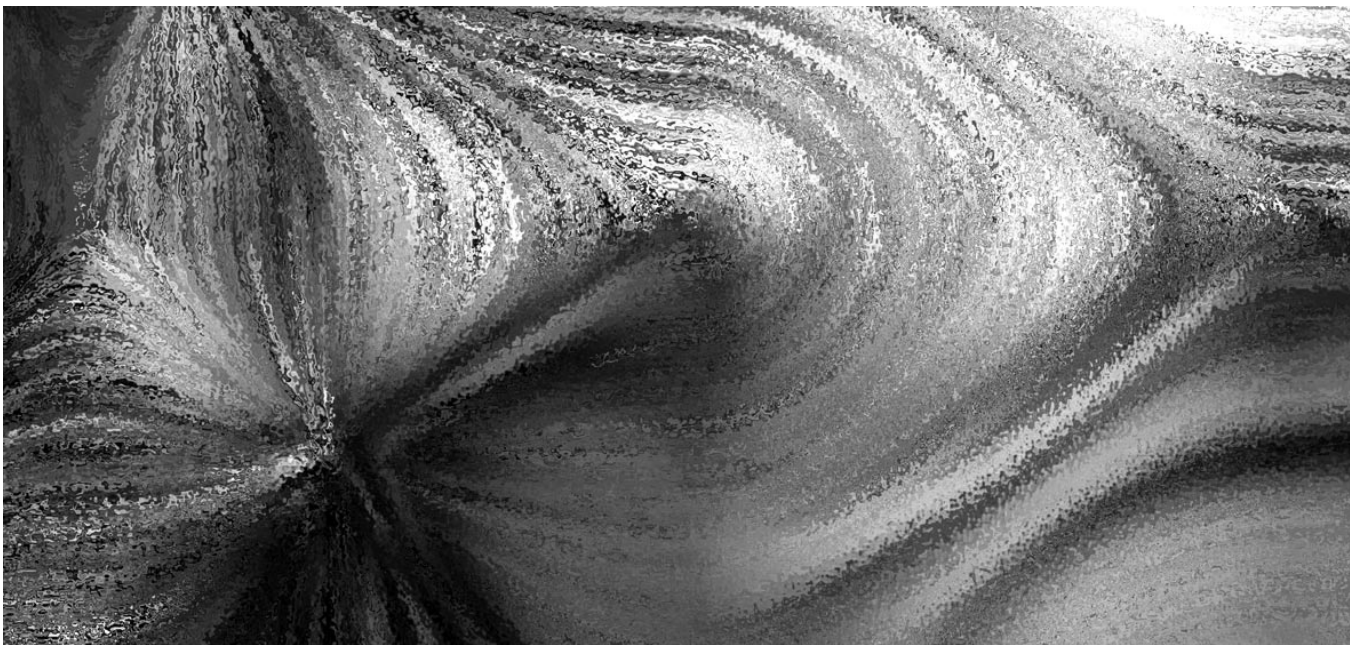
Compare your take off velocity result with that obtained in 65 and from the evidence of this comparison decide:

which of the two techniques appears to have greater potential if the jumper wishes to jump as high as possible?

68

What other factors might determine the success of the jump?

ASSIGNMENT SIX
CENTRE OF GRAVITY



CENTRE OF GRAVITY

The pupose of this assigment is to consider the concept of the centre of gravity within the context of the sports performer. There are five categories of task and some simple equipment is needed. Read through the instructions before undertaking the tasks. For this task you need to work in groups of three or more.

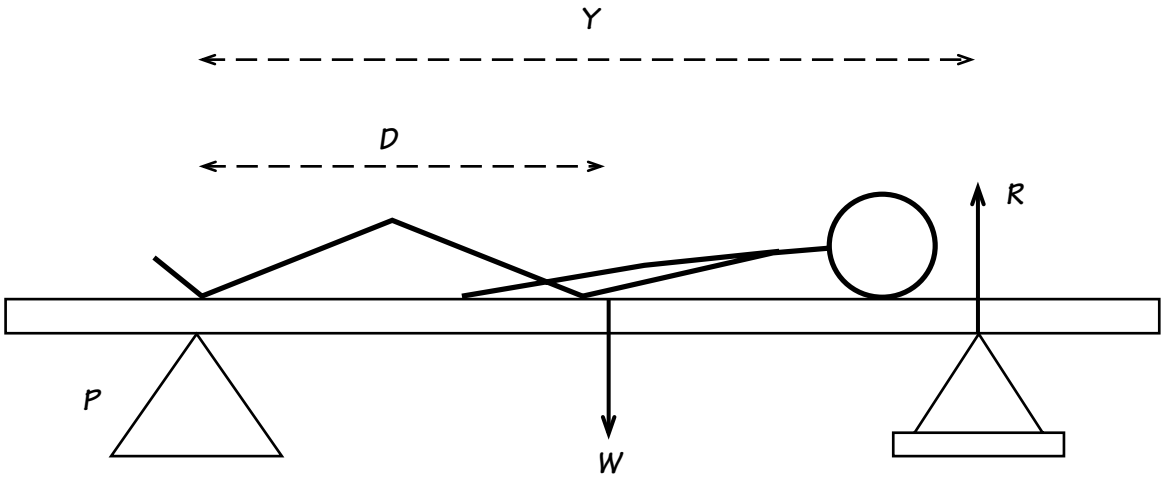
69 Answer

Members of the group should calculate the position of the centre of gravity of subjects as indicated in the instructions below.

Obtain a reading of each students weight. If the scales used give a value of weight in kilograms this will need to be converted to Newtons by multiplying the recorded result by 9.8 $m \cdot s^{-2}$.

Position a stiff rigid board, approximately 2.0 metres long, between two supporting pivots. Place a set of weighing scales underneath one of the supporting pivots. With the board, pivots and scales in position, re-set the scales to a zero reading. Lie on the board in a supine position with arms by side. The heels of the person lying on the board should be level with the pivot that is not supported by a set of scales. At this point the experimental set up should look like that shown in Figure 5.

Figure 5 Position of subject on board as seen from the side.



In Figure 5 the notation is identified as follows: P = Pivot; W = Weight of the person lying on the board; R = Reaction force exerted by scales on board; D = Distance the subject's weight acts from the pivot that is (distance of C of G from pivot); Y = The distance between pivots.

In the experiment, with the person in position, the board is in a state of rotational equilibrium, ie. the clockwise acting moments (torques) must

be equal to the anti-clockwise moments (torques). For this situation the person's weight is generating a moment in a clockwise direction about the pivot P equal to W × D and the reaction force R is generating an anticlockwise moment about P equal to R × Y. As these moments must be equal but opposite in direction the following equation can be written:

$$W \times D = R \times Y$$

In this equation, D represents the distance the centre of gravity of the subject lying on the board is from the pivot, and as the feet of the subject are positioned level with the pivot, this can then be thought of as the position of the centre of gravity from the base of the subject's feet. The equation can be rearranged to give D as follows:

$$D = \frac{R \times Y}{W}$$

Using the information provided, find the position of the centre of gravity for the subject with: both arms by the side; one arm by the side and one arm overhead; and both arms overhead. Remember that you will need to record the reaction force from the scales in Newtons, and that you will also require the distance between the pivots in metres.

70 Answer

When you have calculated the above, look at the results and decide in which direction, and by how much, the centre of gravity moved for the one arm overhead situation.

71 Answer

Repeat the process for the two arm overhead situation.

72 Answer

Which member of the group showed the largest movement of the centre of gravity and why?

73 Answer

What are the possible sources of error in the experiment?

74 Answer

Explain how you think the information gained in this experiment could be used by a sports performer who wished to improve his/her jump and reach performance, e.g. basketball tip-off, rugby line out.

75 Answer

Using the same apparatus work out by how much the centre of gravity moves horizontally when a sprinter moves from the 'on your marks' position to the 'set' position.

76 Answer

Using the same apparatus confirm that the line of gravity falls within the base of someone performing a headstand.

77 Answer

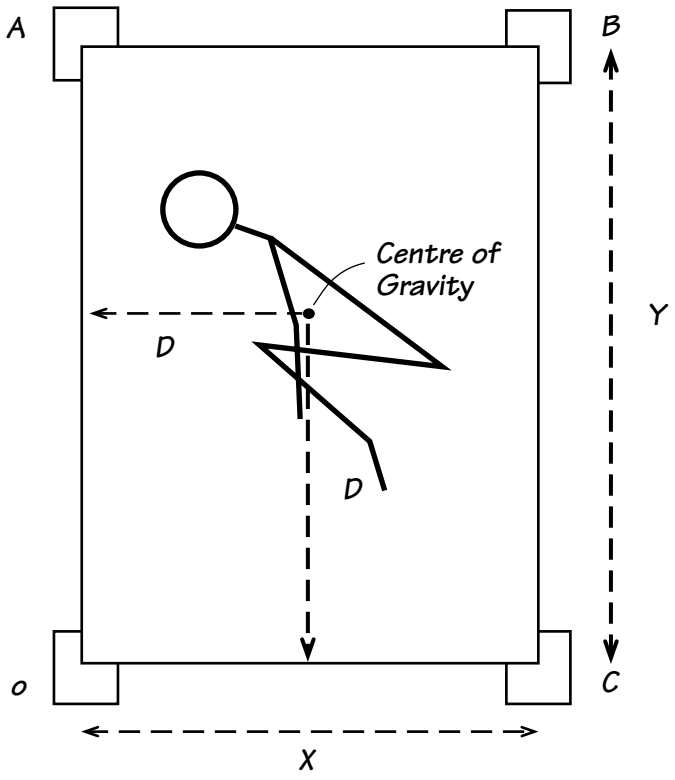
In the previous tasks only a single positional value has been obtained when locating the centre of gravity. In the following task the centre of gravity is located as a set of x and y coordinates, and therefore is a two dimensional location. The general principles behind this experiment are the same as those in the previous tasks. For this task you will need to work in groups of three or more.

Obtain a reading of each student's weight. If the scales used give a value of weight in kg this will need to be converted to Newtons by multiplying the recorded result by 9.8 $m \cdot s^{-2}$. Position a large rigid board wih approximate dimensions of 2.0 meters by 1.4 metres on four corner pivots, each of which is resting on a set of scales. With the board in position reset the scales to a zero value.

Get the subject to lie in the centre of the board on his/her side, and to adopt a position which mirrors that used by a gymnast performing a tucked somersault. With the subject remaining as still as possible, record the readings on the four corner scales, and then chalk an outline of the subjects body position. When the outline is completed the subject can leave the board. (The use of a chalk outline is rather cumbersome, but the alternative is for the subject to remain in the same position whilst the calculations are undertaken. For simple positions this is possible but for more complex techniques the subjects will find it difficult to remain still).

The experimental setup with the subject in position should be as shown in Figure 6

Figure 6 Position of subject in centre of board as seen from above.



The notation used in Figure 6, 7 and 8 is as follows:

O = Origin corner.

A, B, C = Corner labels.

Ra, Rb, Rc and Rd = Reaction forces of scales at corners.

X = distance between pivots A to B and O to C (width).
D = Perpendicular distance of C of G from O-A axis.

Y = distance between pivots O to A and B to C (length)E = Perpendicular distance of C of G from O-C axis.

The board is in rotational equilibrium, and therefore as before equations can be derived to represent this situation.

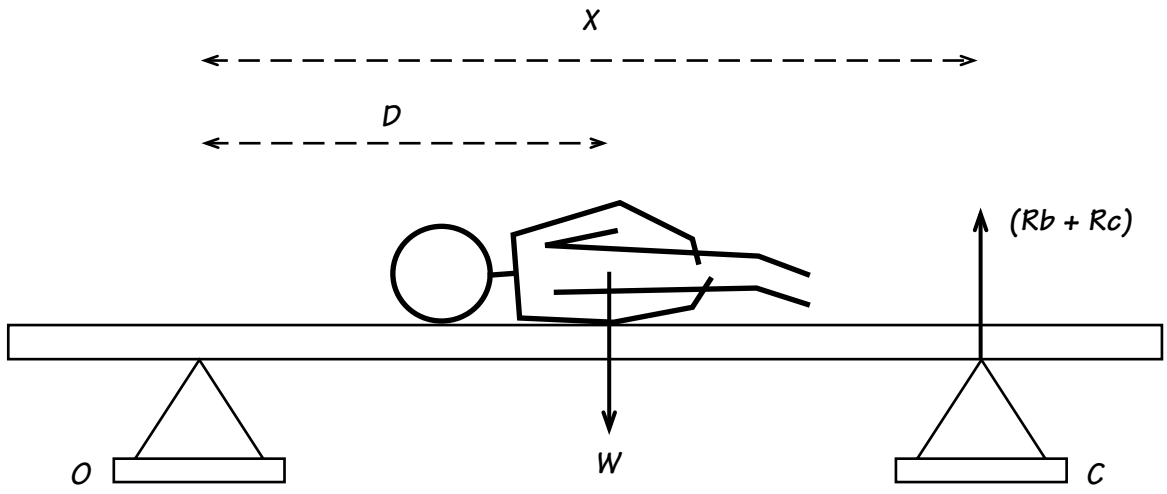
Taking an axis which passes from O to A, the clockwise moments will be equal to W × D (where W is weight of subject), and the anti clockwise moments will be equal to (Rb + Rc) × X. As the board is in rotational equilibrium the formula can be written as:

$$W \times D = (Rb + Rc) \times X$$

The value of D is the perpendicular distance the centre of gravity lies from the O - A axis, and therefore the equation can be rearranged to give:

$$D = \frac{(Rb + Rc) \times X}{W}$$

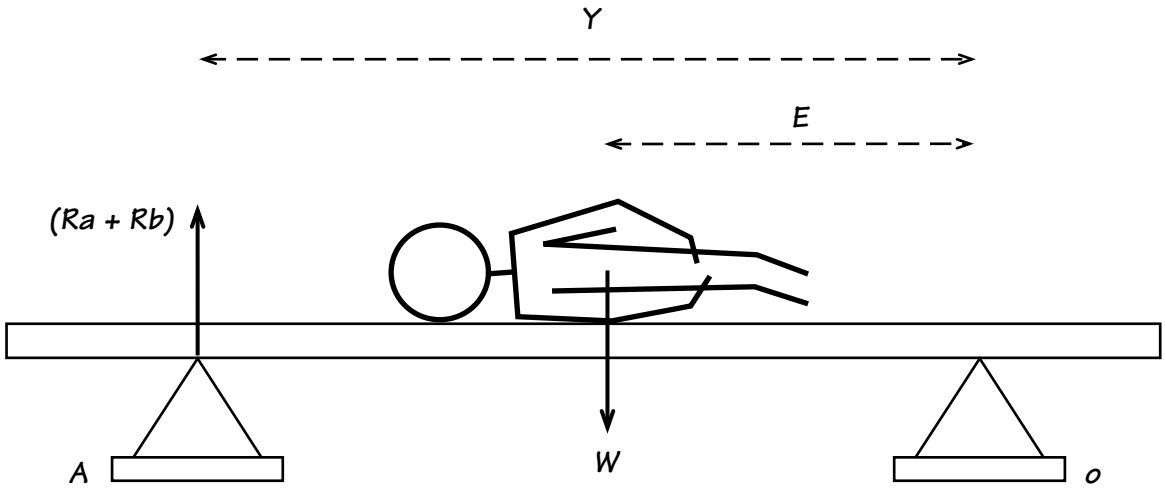
Figure 7 Moments of force in rotational equilibrium about axis O-A.



Taking now an axis which passes from O to C, the clockwise moments will be equal to (Ra + Rb) × Y, and the anti clockwise moments will be equal to W × E (where W is weight of subject). As the board is in rotational equilibrium the formula can be written as:

$$(Ra + Rb) \times Y = W \times E$$

Figure 8 Moments of force in rotational equilibrium about axis O-C.



The value of E is the perpendicular distance from the O-C axis and therefore the equation can be rearranged to give:

$$\frac{(Ra + Rb) \times Y}{W} = E$$

The centre of gravity of the subject can now be located by using O as the origin, and measuring the distances D and E along the O-C, and O-A axes, respectively. The perpendiculars drawn from these points on the axes intersect at the centre of gravity. The chalk outline of the body position can then be used to observe the position of the centre of gravity relative to the gymnast body position. For each member of the group calculate the centre of gravity for a tucked somersault, piked somersault, and straight/hollow somersault positions. When all the results have been calculated note the change in position of the centre of gravity relative to body shape.

What is the significance of the centre of gravity, and body positions, to the moment of inertia of the gymnasts for the three different body shapes?

78 Answer

What are the potential sources of error/limitations in the experiment?

79 Answer

Repeat the above procedures for the take off position in the long jump, and explain the significance of the centre of gravity position.

80 Answer

Repeat the above procedures for the clearance position in the Fosbury flop, and explain the significance of the centre of gravity position.

81 Answer

This task requires the use of a video of sports performance, video player with a stills facility and monitor, and some overhead transparencies.

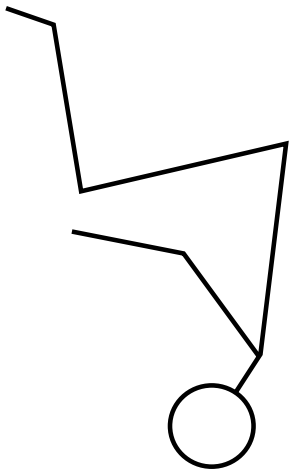
Construct a centre of gravity mannikin, by reference to the instructions given in Anatomy, Mechanics and Human Motion by Hay and Reid (1988) p 397.

Obtain a video of a sports performance which shows a technique which can reasonably be modelled to be taking place in two dimensions, and that contains a flight phase, e.g. long jump, somersault, simple vault etc. If you are able to record a video of your own performance, try to make sure that the camera is perpendicular to the action, that the image is as large as possible whilst still being able to see the technique, and that you use a tripod to ensure the image is as clear as possible.

When you have obtained the video, attach the overhead transparency to the monitor and play the tape back. Advance the tape so that you see a number of stills of the event. Check that you can get at least 7 or 8 still images of the complete technique.

Starting from the first still record on the overhead transparency, mark the following points on the performer's body: top of head, shoulder, elbow, wrist, hip, knee and ankle. Join up the points on the body to give a stick figure as shown in **Figure 9**.

Figure 9 Stick figure constructed as described.



Repeat this for all the stills until you have a series of stick figures on the overhead tranparency.

Take your transparency, and using your mannikin to help make the judgement, mark the centre of gravity for each position.

Look at the overall pattern that the path of the centre of gravity makes. Does it conform to what you would expect it to look like?

Explain what the theory of projectiles indicates the trajectory of the centre of gravity should look like.

82 Answer

Discuss any potential sources of error in the experiment.

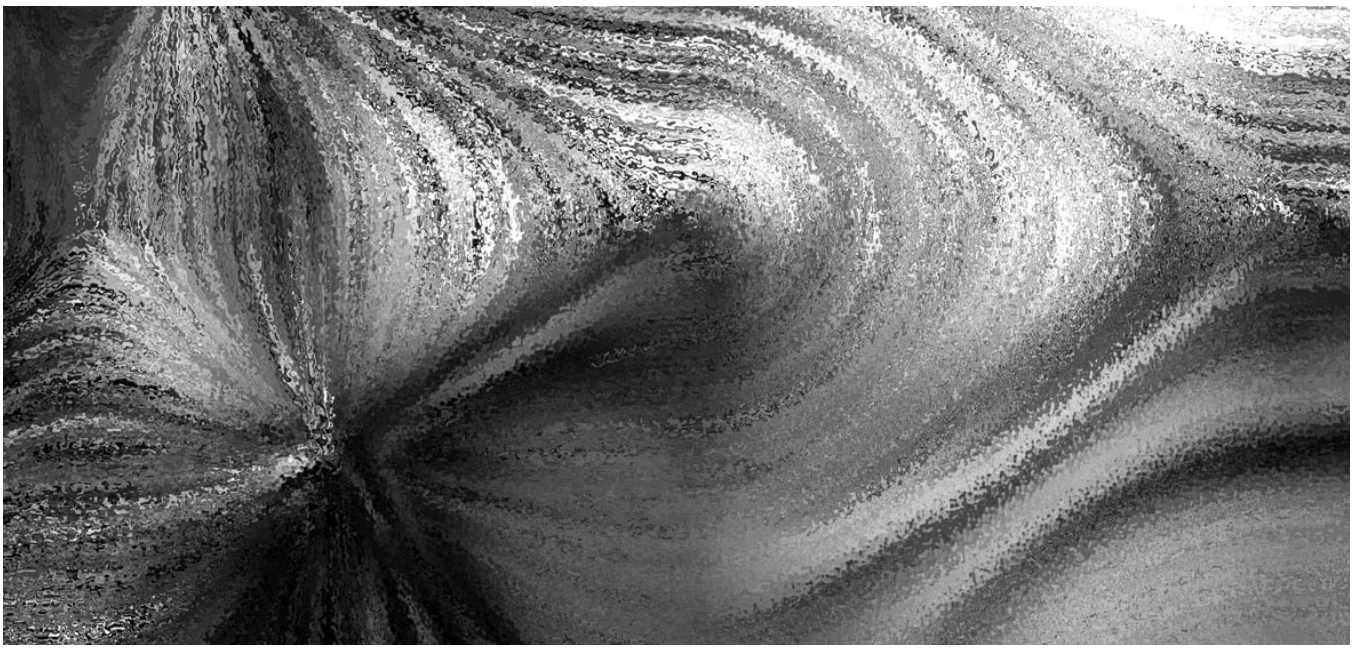
83 Answer

Repeat the above procedure for sports techniques where balance/stability is important. e.g., headstand, handstand, arabesque, swimming starts, running starts, etc. Compare your centre of gravity results with the theoretical predictions for such techniques.

84 Solution not supplied

Using any of the techniques described in the previous tasks: work out the position of the centre of gravity for any of the events shown in figures 21 - 25 at the end of the Assignments section. Before undertaking any experimental method, mark on your own estimate for the positions shown, and then on completion of the experimental method, note any difference in the calculated and estimated centre of gravity location.

ASSIGNMENT SEVEN
FORCE & CHANGES IN MOTION



FORCE & CHANGES IN MOTION

The purpose of this investigation is to consider the relationship between **force** and changes in motion. More specifically it emphasises the relationship between force, and descriptive parameters such as **displacement, velocity,** and **acceleration**. There are two tasks to undertake. The first considers how force values can be derived from acceleration data (which has itself been derived from position, displacement and velocity data). The second task considers the reverse process, where from a known set of force data, acceleration, velocity and displacement values are derived. It should be noted from the outset that when describing the jumper's motion, it is the motion of the centre of gravity of the jumper that is being referred to. The tasks in this sheet incorporate some of the principles previously investigated in Assignment Five.

85 Answer

If original position data are known, and the associated time information is available, by a process of numerical differentiation, both average velocity and average acceleration values can be derived. It may now be seen that if acceleration values can be determined, then Newton's Second law ($F = m \times a$) indicates that information about the net force that was acting to cause the accelerations, will also be available. In the case of the vertical jump data, if air resistance is ignored, then the net force at any moment during the take off phase, will be the resultant of the gravitational and ground reaction force. If it is known that the subject has a mass of 70 kg then the gravitational force (weight) can be calculated. As the gravitational component of the net force remains constant, the remaining force must be that associated with the ground reaction force.

Using the formula: Weight = mass × acceleration due to gravity calculate the weight of the jumper (taking the acceleration due to gravity as 9.8 $m \cdot s^{-2}$)

86 Answer **Complete Table 14 with the following column headings:**

Table 14

Col 1 Time (s)	Col 2 Pos't. (cm)	Col 3 Displ' (cm)	Col 4 Displ' (m)	Col 5 Vel' ($m \cdot s^{-1}$)	Col 6 Change Vel' ($m \cdot s^{-1}$)	Col 7 Ave'Acc' ($m \cdot s^{-2}$)	Col 8 F = ma (N)	Col 9 GRF (N)
0.00	102.00							
		0.00	0.000	0.00				
0.05	102.00							
		0.00	0.000	0.00				
0.10	102.00							
		– 1.00	– 0.010	– 0.20				
0.15	101.00							
		– 1.00	– 0.010	– 0.20				
0.20	100.00							
		– 2.00	– 0.020	– 0.40				
0.25	98.00							
		– 4.00	– 0.040	– 0.80				
0.30	94.00							
		– 6.00	– 0.060	– 1.20				
0.35	88.00							
		– 6.00	– 0.060	– 1.20				
0.40	82.00							
		– 4.00	– 0.040	– 0.80				
0.45	78.00							
		– 3.50	– 0.035	– 0.70				
0.50	74.50							
		– 2.00	– 0.020	– 0.40				
0.55	72.50							
		0.00	0.000	0.00				
0.60	72.50							
		3.00	0.030	0.60				
0.65	75.50							
		6.00	0.060	1.20				
0.70	81.50							
		11.00	0.110	2.20				
0.75	92.50							
		13.00	0.130	2.60				
0.80	105.50							
		12.00	0.120	2.40				
0.85	117.50							

87 Answer

Calculate the change in velocity for each of the time intervals, and enter in Column 6 of Table 14.

88 Answer

Calculate the average acceleration values for each of the time intervals and enter in column 7 of Table 14.

Note that your results may show quite a variable pattern in the data. The variability in the acceleration pattern reflects the variation in force, but is also likely to contain some errors due to the process of actually calculating acceleration. This is frequently the case when the original data has come from film or video.

89 Answer

By multiplying the average acceleration values by the mass of the subject, using the formula:

$F = m \times a$

Calculate the net average force associated with the calculated acceleration values, and enter in column 8 of Table 14.

90 Answer

If: Net Force = mass × acceleration

and: Net force = ground reaction force – gravitational force (weight)

then: Ground reaction force – gravitational force (weight) = mass × acceleration

Therefore the formula can be rearranged as:

Ground reaction force = (mass × acceleration) + weight

Using the above formula, calculate the value of the ground reaction force component for each of the calculated average acceleration values, and enter in column 9 of Table 14.

91 Answer

Plot a graph to show the ground reaction force v time (Solutions Figure S19).

The stages in the process are now complete as it has been shown that from original position (and time) data, displacement, velocity, acceleration and force values can be derived.

92 Answer

The starting point for this task is the data in **table 15**.

Table 15 Data representing vertical ground reaction force values recorded through the take off phase of a vertical jump for a jumper of mass 70kg (jump 1).

Col 1 Time (s)	Col 2 GRF (N)	Col 3 Net Force (N)	Col 4 Accel' ($m \cdot s^{-2}$)
0.00	686		
0.04	670		
0.08	645		
0.12	627		
0.16	510		
0.20	412		
0.24	510		
0.28	531		
0.32	554		
0.36	598		
0.40	654		
0.44	771		
0.48	1022		
0.52	1306		
0.56	1611		
0.60	1704		
0.64	1660		
0.68	1638		
0.72	1616		
0.76	1584		
0.80	1420		
0.84	700		
0.88	0		

This data represents the ground reaction forces recorded on a force platform at a number points during a vertical jump take off. In order to simplify this part of the task, the data has been sampled to give a few points, so that the principle can be demonstrated. In a 'real' set of data

which had been obtained from a force platform, then many more points would be recorded (e.g. with a vertical jump take off often lasting approximately one second, a typical sampling rate of 500 Hz, would produce 500 force values!).

The data in Table 15 shows the vertical ground reaction force values at a number of points during the period of the take off. In order to calculate the net force acting on the jumper, the value for the jumper's weight needs to be subtracted from each of the vertical ground reaction force values.

Undertake the necessary calculations and add a 'Net Force' column (Column 3) to Table 15

(Mass of subject = 70 kg, acceleration due to gravity = 9.8 $m \cdot s^{-2}$)

---

93 Answer

Because Newton's Second Law defines the relationship:

$F = m \times a$

If the net force values are divided by the subject's mass:

$\frac{F}{m} = a$

then the associated acceleration is obtained.

Undertake the necessary calculations and add an acceleration (column 4) to Table 15.

---

94 Answer

Plot a Net vertical force v time graph from the data now present in Table 15 (Solutions Figure S20).

Use graph paper based on 1 cm squares, use a vertical scale such that 100 Newtons is represented by 1 cm, and a horizontal scale such that 0.04 seconds is represented by 1 cm.

Draw a smooth line through the points. Remember that because you have taken the subject's weight into account, that you should expect some of the net force values to be negative.

95 Answer

The area under a force v time graph represents the impulse generated by the force (see Assignment Five). A formula can be written, relating the Impulse to the change in momentum experienced during the application of the force, and where the mass of the object was constant then this could be written as:

$$F \times t = m(v_f - v_i)$$

In the case of the vertical jump take off, if the area under the curve can be calculated, then dividing by the subject's mass will reveal the change in velocity experienced by the jumper i.e.

$$\frac{F \times t}{m} = (v_f - \mathrm{v_i})$$

In order to calculate the area under the curve, a simple square counting method should be used.

Calculate the area represented by one unit centimetre square as shown on your graph in terms of the impulse it represents, and record the value in newton seconds (N·s).

96 Answer

You now have a value in newton seconds for a one centimetre square, and you must now work out how many squares represent the positive area of the graph, and how many squares represent the negative area.

Probably the easiest method of doing this is to first shade the whole squares that are contained completely within the area. Then looking at the remaining area, shade elements of squares which in your judgement when combined would make a complete square. Continue the process until the complete area under the curve is shaded. Note that you may decide that there is a half or some other fraction of square remaining, and this needs to be incorporated into your final total. Keep a record of the total number of positive squares, and the total number of negative squares.

As you now have an estimate of the number of squares making up the positive area, and the negative area, you can calculate: the positive impulse values; the negative impulse values and the associated net impulse.

Multiply the number of 'positive' squares you counted by the impulse value (in newton seconds) you calculated for a single square in stage 3, and record the value.

Multiply the number of 'negative' squares by the impulse value (in newton seconds) you calculated for a single square, and record the value.

By combining the positive and negative impulse values calculate a net impulse value.

The net impulse value when divided by the subject's mass, gives a change in velocity, i.e.

$$\frac{F \times t}{m} = (v_f - v_i)$$

continued....

In the case of the vertical jump the movement started from a stationary position, and therefore the initial velocity is zero. Therefore the change that is calculated for this event reveals the actual take off velocity of the jumper.

Calculate the actual take off velocity of the jumper.

97 Answer

A second set of data is provided for a second vertical jump in Table 16. Using the processes outlined so far:

Add a 'Net Force'column (Column 3) to table 16.

Table 16 Data representing vertical ground reaction force values recorded through the take off phase of a vertical jump of a jumper of mass 78.38 kg (jump 2).

Col 1 Time (s)	Col 2 GRF (N)
0.00	769
0.04	756
0.08	708
0.12	666
0.16	590
0.20	539
0.24	541
0.28	561
0.32	593
0.36	625
0.40	678
0.44	690
0.48	744
0.52	876
0.56	1193
0.60	1562
0.64	1752
0.68	1728
0.72	1679
0.76	1662
0.80	1638
0.84	1315
0.88	0

98 Answer **Add an 'Acceleration' column (Column 4) to Table 16.**

99 Answer **Plot a net vertical force v time graph from the data now present in Table 16 (Solutions Figure S21).**

100 Answer **Calculate the take off velocity for this jump.**

101 Answer **Which jump achieved the higher take off velocity?**

102 Answer The processes used above showed how the change in velocity value could be calculated for the whole of the period of the take off phase. However, in principle, there is no reason why the same method could not be used over different time intervals.

In this way the change in velocity experienced by the jumper at different points in the jump can be calculated.

Using the data provided for the two jumps, and the techniques outlined above:

Calculate the maximum downward velocity in jump 1.

103 Answer Using the data provided for the two jumps, and the techniques outlined above:

Calculate the maximum upward velocity in jump 1.

104 Answer Using the data provided for the two jumps, and the techniques outlined above:

Calculate the maximum downward velocity in jump 2.

105 Answer Using the data provided for the two jumps, and the techniques outlined above:

Calculate the maximum upward velocity in jump 2.

Note that the maximum upward velocity is not equal to the take off velocity.

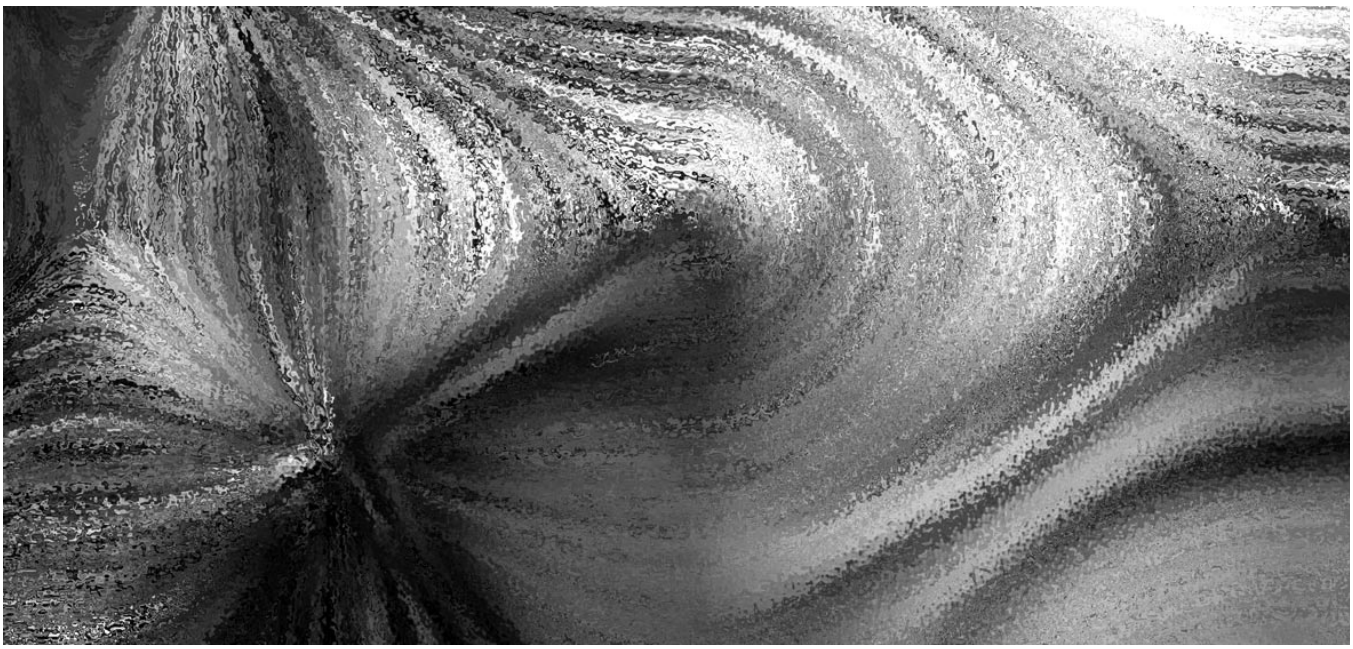
Hint: Peak velocity values will occur at points where acceleration is zero (excluding the starting position). Acceleration values will be zero where the net force acting on the jumper is also zero, ($F = m \times a$). To calculate peak velocity values, the area under the curve up to the points where the net force acting on the jumper is zero, will need to be estimated/calculated. The principles outlined above show that it would be possible to work out the change in velocity over a series

of small time intervals. In this way a 'history' of the way the jumper's vertical velocity changed over the period of the jump could be built up. If this time based history of vertical velocity changes was then plotted on a vertical velocity v time graph, further analysis would be possible, as the area under the vertical velocity v time graph represents the vertical displacement experienced by the jumper. i.e.

$$v = \frac{s}{t} \quad \text{or} \quad v \times t = s$$

The procedures for calculating the area under a velocity v time graph would be the same as those outlined in previous stages. The actual process for deriving displacement values by these methods is very time consuming, and prone to inaccuracy. It is not therefore recommended that the calculations and measurements be completed, but that the principles be thought through and understood. It may be noted that, in practice, sport scientists would use computers and numerical techniques to calculate areas under curves to derive displacement values from force information. The stages in the task are now complete, as it has been shown that from an original force data set, acceleration, velocity and displacement values can be derived.

ASSIGNMENT EIGHT
WORK, ENERGY & POWER



WORK, ENERGY & POWER

The purpose of these tasks is to investigate the concepts of work, energy and power. When a sports performer throws a ball, lifts a weight, throws a discus etc, s/he applies a force to the implement over a distance, and as such does some work. However, it is not just sports implements that can experience work being done on them. In moving their own bodies, sports performers undertake work, and the following task focuses on this aspect of work in sports performance.

106 Answer

Study the data in **Table 17** relating to the take off phase of a vertical jump.

Table 17 Vertical ground reaction force generated, and corresponding vertical velocities of the performer's centre of gravity, during the take off phase of a vertical jump.

Col 1 Time (s)	Col 2 Force (N)	Col 3 Velocity ($m \cdot s^{-1}$)	Col 4 Power (watts)
0.0	685	0	
0.04	585	– 0.04	
0.08	468	– 0.058	
0.12	329	– 0.197	
0.16	207	– 0.423	
0.20	153	– 0.705	
0.24	173	– 0.997	
0.28	363	– 1.231	
0.32	905	– 1.221	
0.36	1162	– 0.981	
0.40	1496	– 0.452	
0.44	1540	0.132	
0.48	1478	0.707	
0.52	1467	1.247	
0.56	1501	1.808	
0.60	1435	2.356	
0.64	1142	2.810	
0.68	0	2.781	

Using the fact that Power is equal to Force × Velocity calculate the Power values for the force and velocity data points provided in Table 17 and enter in Column 4.

---

107 Answer

After reading tasks 108 & 109 and using the scaling suggested, plot a graph of vertical ground reaction force v time during the take off phase of a vertical jump (Solutions Figure S22).

---

108 Answer

Using the scaling suggested in task 109, plot a graph of vertical velocity v time during the take off phase of a vertical jump (Solutions Figure S23).

---

109 Answer

Plot a graph of power v time during the take off phase of a vertical jump (Solutions Figure S24).

Try to draw all three graphs on a single side of sheet of graph paper which has one centimetre divisions, using appropriate vertical scales to ensure that they fit. (Suggested values are: Force: 1 cm = 200 N; Velocity: 1 cm = 0.6 $m.s^{-1}$; Power: 1 cm = 400 W). Use the same scale for time on the horizontal axes of each of the graphs (Suggested value 1 cm = 0.04 s). Make sure that the origins of each graph fall on the same vertical line. Title and label each of the graphs as appropriate.

Observe the three graphs and note that the maximum power output does not necessarily have to coincide with the maximum ground reaction force and/or maximum velocity.

---

110 Answer

As 'Power = force × velocity', it may be noted that this equation could be written as:

$$\text{Power} = \text{force} \times \frac{\text{displacement}}{\text{time}}$$

But 'force × displacement' is the definition of 'work' and therefore:

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

If the formula is rearranged to make work the subject, this gives:

$$\text{Work} = \text{power} \times \text{time}.$$

Inspection of the 'power v time' graph you have drawn in Task 109 will show that 'power × time' can be represented by the area under the curve, and therefore this area represents the work done during the take off phase of the vertical jump.

By following the steps set out below it is possible to calculate the work done.

Note that your 'power v time' graph has an area below the zero line, and an area above the zero line. The area below should be treated as negative, and the area above treated as positive. It is the sum of these areas which is the required value.

There are a variety of mathematical methods that could be used to calculate the area under the curve, but a simple square counting method will be explained which can give a reasonable approximation. To get a better approximation the graph can be redrawn at a larger scale.

Calculate the work value represented by one unit square on your graph. If you are using the original small scale graph and the suggested scale values, this will be a one centimetre square, and the result derived from multiplying 400 W by 0.04 s. Record your result as the work (joules or newton metres) represented by one unit square.

Working on your graph shade the number of complete unit squares, and make a record noting how many squares there are in the negative area, and how many are in the positive area.

Having identified the number of complete squares, you must now estimate the remaining area by combining 'part' squares to give notional complete squares. As the estimates are made, shade the areas to avoid double counting, and add the results of the estimation to the record of the number of negative and positive squares. At the end of the exercise the whole of the area under the curve should be shaded.

Take the total number of squares representing the negative area and multiply this by the previously calculated work value for one unit square, and:

Calculate the work represented by the negative area.

---

111 Answer

Repeat the above procedure and calculations for the squares representing the positive area of the graph and:

Calculate the work represented by the positive area.

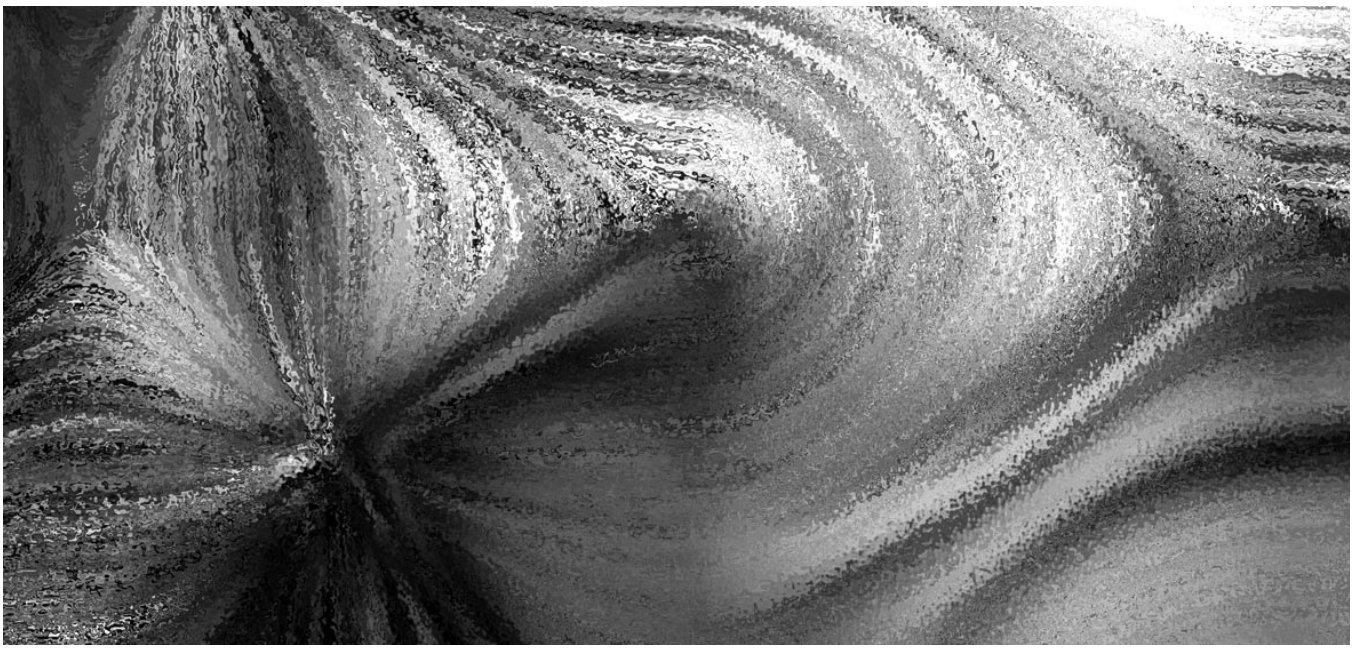
---

112 Answer

Work out the total amount of work done during the take off, by summing the 'negative' and 'positive' area work values calculated in the previous stages.

It should be noted that even ignoring the measurement errors that are likely to have arisen during the calculation, the final work figure will probably be an under estimation of work/energy value, as some of the energy expended will have been 'lost' in friction at joints, heat in muscles etc.

ASSIGNMENT NINE
ANGULAR DESCRIPTORS OF MOVEMENTS



ANGULAR DESCRIPTORS OF MOVEMENTS

The purpose of this investigation is to use a simple method to calculate the angular velocity of a sports performer undertaking a front somersault. You will need to use the stick diagram or kinetogram (Figure 24 provided in the Appendix) recorded from a video of a student performing a forward somersault off a spring board. The time interval between each position shown is 1/25th of a second.

In the investigation, it is assumed that the trunk segment will give an approximate value to the angular velocity of the body as a whole. This is a reasonable assumption when the body segments remain fixed relative to one another, but it should be recognised that there are limitations to this approach for phases of the technique where segments are moving relative to one another. All movements are assumed to occur within a single plane.

---

113 Answer

Using a protractor, measure the position of the trunk segment of the gymnast relative to the reference axis, for each of the positions shown. Measure from a vertical reference axis in an anti clockwise direction.

Record the results in Column 2 of Table 18.

---

114 Answer

Work out the angular displacement between successive positions and record the results in Column 3 of Table 18.

Note that the displacement is recorded between the position data.

---

115 Answer

Divide each of the values recorded in Column 3 by 1/25th of a second to get an average angular velocity value for each time interval, and record the results in Column 4 of Table 18.

Note once again that the value is recorded at the mid interval value.

Table 18 Data for the trunk segment of the gymnast performing a forward somersault off a springboard relative to the reference axis.

Col 1 Time (s)	Col 2 Angular Position (degrees)	Col 3 Ang' Displ' (degrees)	Col 4 Ang' Vel' (deg·s^{-1})
0.00			
0.04			
0.08			
0.12			
0.16			
0.20			
0.24			
0.28			
0.32			
0.36			
0.40			
0.44			
0.48			
0.52			
0.56			
0.60			
0.64			
0.68			
0.72			

116 Answer

Plot a graph of angular velocity of trunk segment v time for your data of the front somersault (Solutions Figure S25).

Record angular velocity on the vertical axis, and time on the horzontal axis. When plotting your data, record the average angular velocity values at the midpoint of the time interval. When all points are plotted, draw a smooth line that passes through or close to the points, so that the trend in the angular velocity is apparent. Label the axes and title the graph appropriately.

117 Answer

Study your graph, and consider the differences between the actual trace obtained for the trunk segment and the theoretical shape of the angular velocity trace for the whole body.

118 Answer

The data in Table 19 relates to the lower leg segment in a kicking action. The data were recorded with frames at 1/50 second intervals, but has been sampled to consider every other frame (ie time interval of 1/25th second). The angles were measured according to the convention in Figure 10.

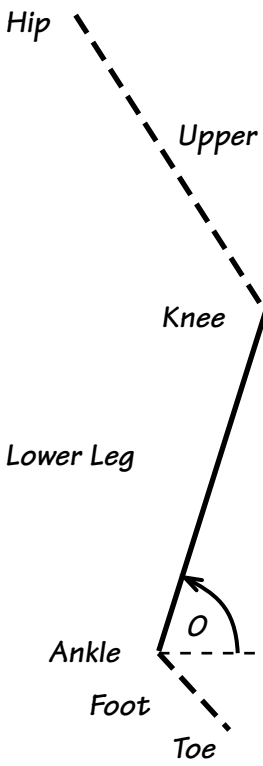


Figure 10 Angle convention for measurement of lower leg segment.

Table 19 Data relating to the lower leg segment in a kicking action.

Col 1 Frame	Col 2 Angle (degrees)	Col 3 Ang' Dis' (degrees)	Col 4 Ang'. Vel' ($deg \cdot s^{-1}$)
1	65.8		
3	92.2		
5	103.6		
7	95.6		
9	72.1		
11	53.8		
13	44.8		
15	42.3		
17	22.3		
19	– 3.5		
21	– 23.2		
23	– 27.6		
25	– 2.4		
27	34.3		
29	64.9		

Using the procedures described previously, and the data supplied in Columns **1 and 2** of **Table 19**:

Calculate the angular displacement for the lower leg segment in the kicking action, and enter the values in Column 3 of Table 19.

---

119 Answer

Calculate the angular velocity for the lower leg segment in the kicking action, and enter these in Column 4 of Table 19.

---

120 Answer

Plot an angle v time graph from data in Table 19 (Solutions Figure S26).

---

121 Answer

Plot an angular velocity v time graph of your results (Solutions Figure S27).

Compare the graph with the one shown for the upper leg during the same time period, which is shown in Figure 4.7 on page 92 of 'Mechanics and Sport Performance' by Peter Walder; Feltham Press.

---

122 Solution not supplied

The diagrams shown in the Appendix show a variety of events where segmental angular positions are shown. Using the procedures described previously, select a segment, and record its angular position for each of the body positions shown. All movements are assumed to occur within a single plane.

Using this data plot and calculate the associated angular velocity values.

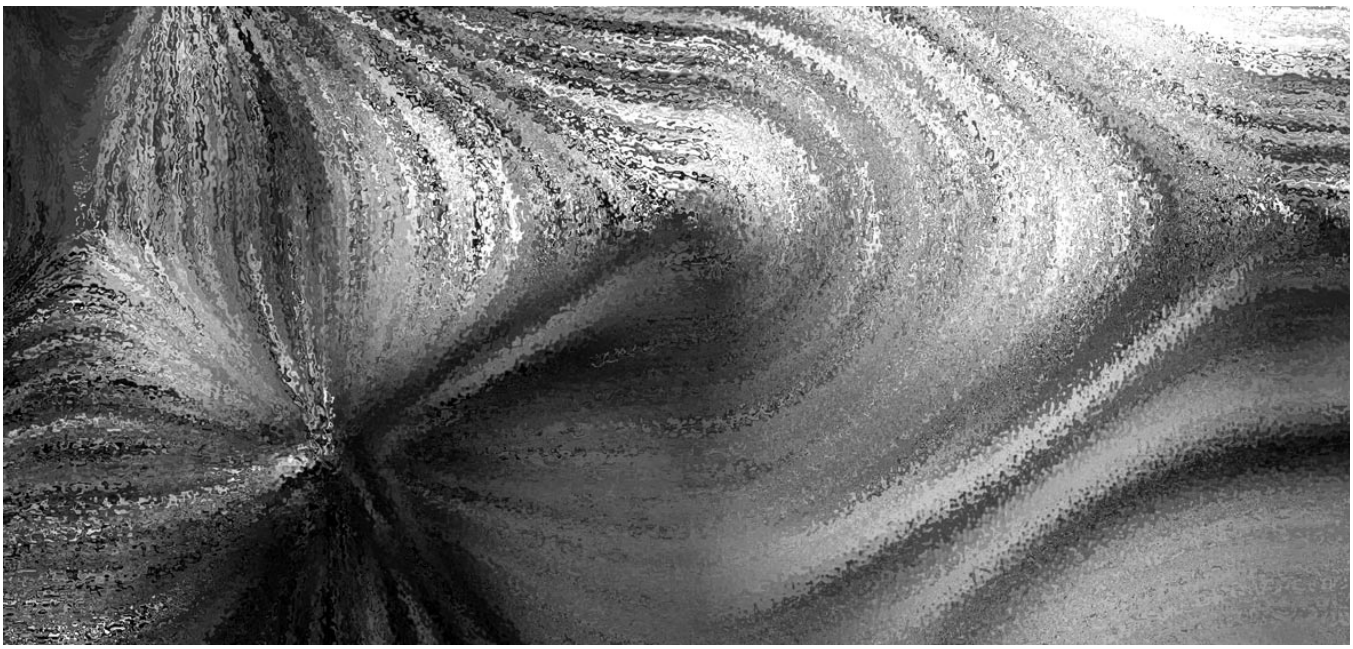
---

123 Solution not supplied

Plot a graph of angular velocity v time.

When measuring and recording angular positions, you will need to decide upon a reference line from which to measure your angles.

ASSIGNMENT TEN MOMENTS/TORQUES



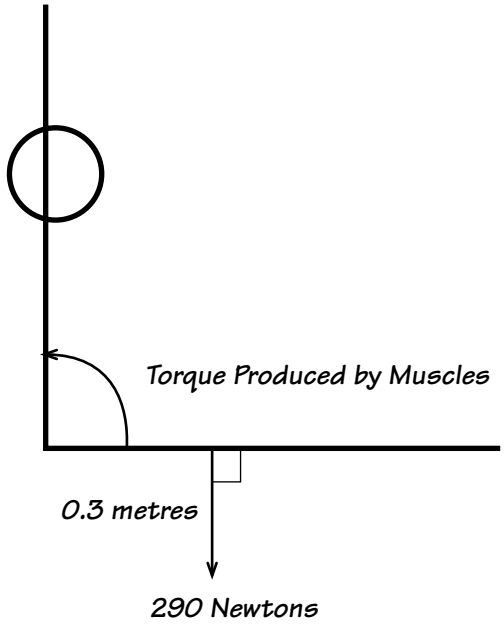
MOMENTS/TORQUES

The purpose of this set of tasks is to consider the concept of torque and moments. The questions involve examples from situations where the torque generating forces are both within the body, and external to the body.

124 Answer

Figure 11 represents someone hanging from the wall bars in a 'half lever' position, with the top and bottom halves of the body perpendicular to one another.

Figure 11 Force and moment arm acting in a half lever.



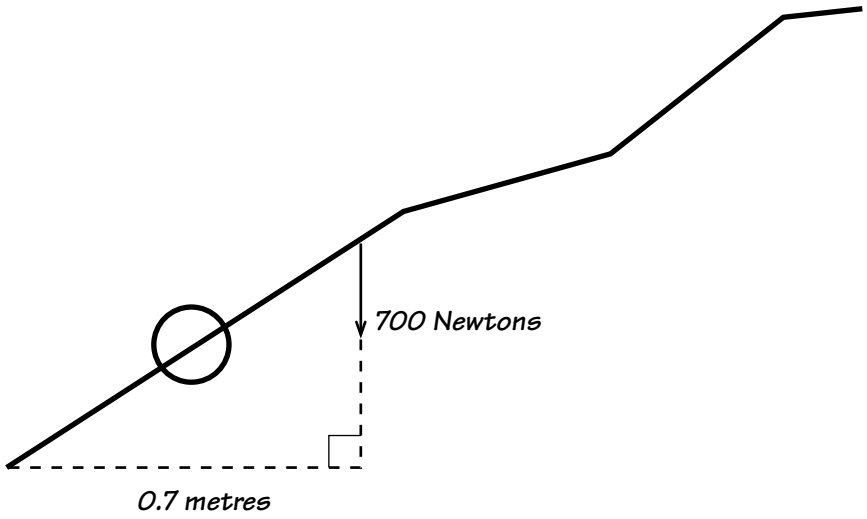
What is the size of the turning effect (torque) being produced by the muscles crossing across the front of the hip joint?

Note that any counter influence of tension in muscle acting across the posterior side of the hip joint are ignored, and the hip is assumed to be the pivot.

125 Answer

Figure 12 represents a gymnast performing a giant swing on the high bar.

Figure 12 Force and moment arm at one point in time during a giant swing.



Assume that the gymnast's body is kept rigid, and that friction forces at the bar, and air resistance can be ignored.

Calculate the moment of force acting at the instant shown.

126 Answer

At what point will the gymnast experience the greatest torque acting in the direction of the swing?

127 Answer

At what point will the gymnast experience the greatest torque acting against the direction of swing?

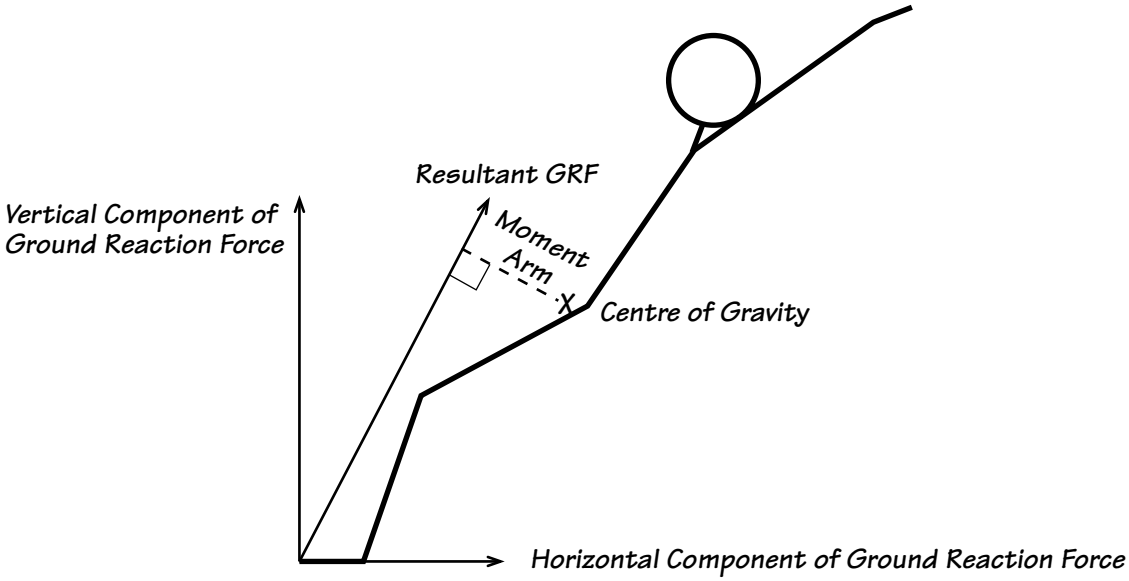
128 Answer

At what point during the swing does the gymnast experience a zero torque?

129 Answer

Figure 13 shows a gymnast during the take off phase of a backflip. The resultant ground reaction force has a magnitude of 1000 Newtons, and the moment arm (that is the perpendicular distance between the centre of gravity and the line of action of the force) is equal to 0.055 metres.

Figure 13 Resultant ground reaction force (and components) and moment arm for one instant during a back flip take off.



For the instant shown, and taking anti clockwise as the positive direction:

Calculate the torque being generated by the ground reaction force.

130 Answer

It is known that the point of application of the force is at coordinate (0.1, 0.0), and the centre of gravity is at (0.45, 0.8) with reference to an abitrary origin in the saggital plane.

Calculate the torques being generated by the vertical and horizontal ground reaction forces respectively.

Note that coordinates are given in metres, and the resultant ground reaction force is acting at 70° to the horizontal.

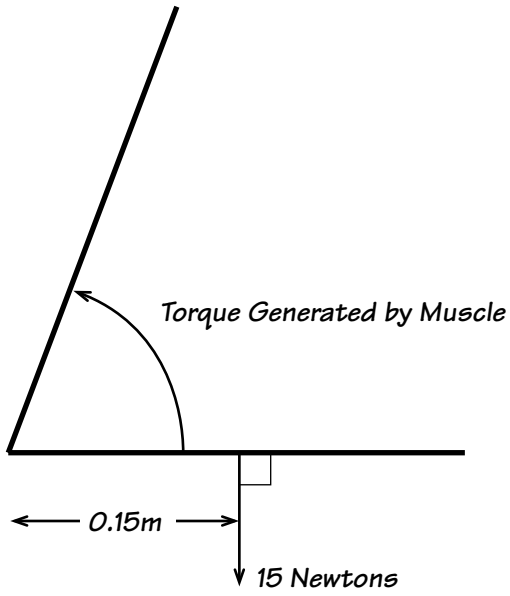
131 Answer

Confirm that the sum of these calculations gives the same result as in 129.

132 Answer

Figure 14 represents the lower and upper arm with the pivot at the elbow.

Figure 14 Force and moment arm generating torque.



It is assumed that the arm is held in a stationary position:

What must be the magnitude of the turning effect being produced by the bicep muscle?

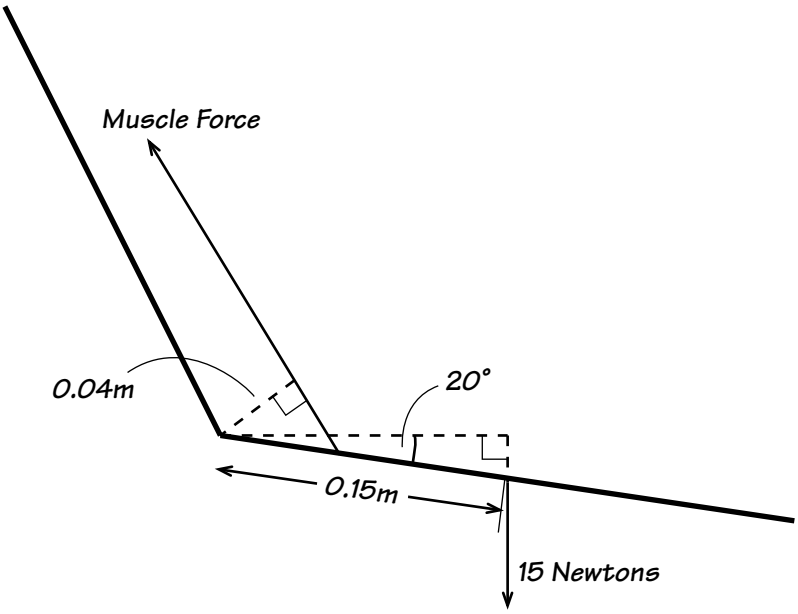
133 Answer

It is known that the perpendicular distance between the pivot at the elbow and the line of action of the force being generated by the bicep muscle is 0.03 metres:

Calculate the magnitude of the force generated by the biceps.

134 Answer

Figure 15 Showing the arm of an athlete being held in a stationary position. The magnitude of the weight of the forearm is 15 Newtons, and the moment arm of the muscle force is equal to 0.04 metre.

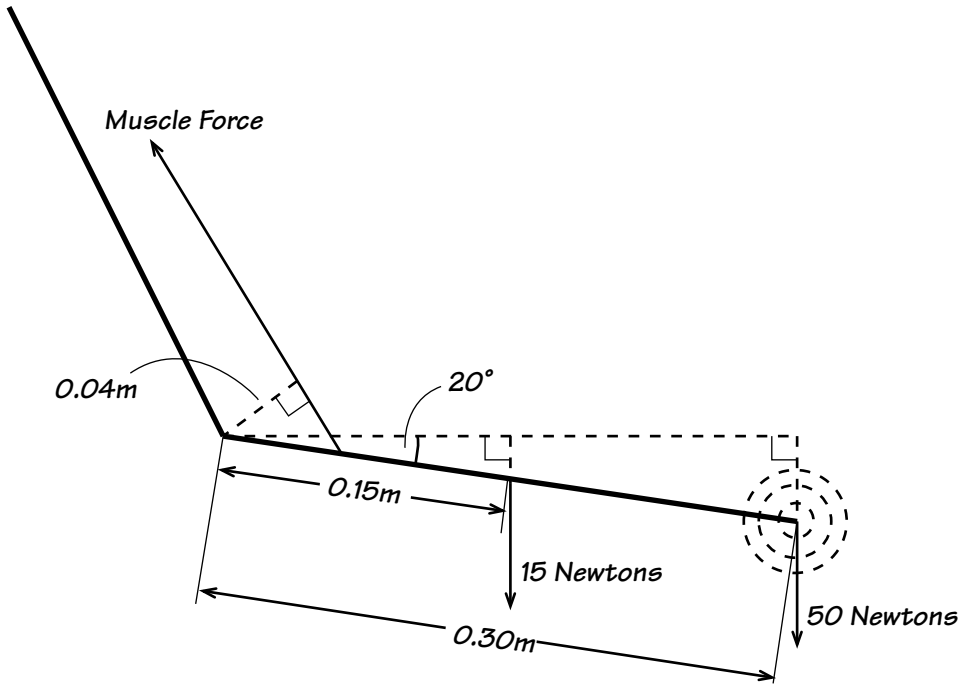


Using the information provided in the diagram:

Calculate the magnitude of the force that is being generated by the bicep muscle.

135 Answer

Figure 16 Showing the athlete holding a 5 kg barbel and maintaining the same position.



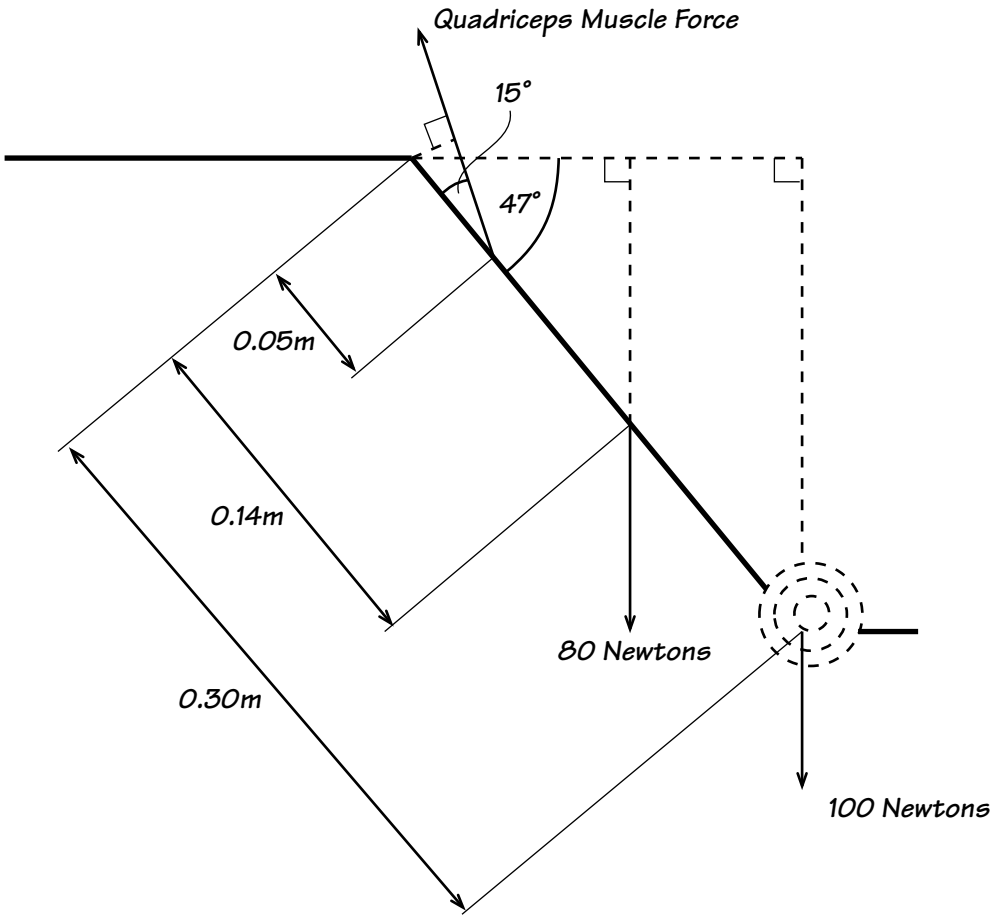
What will be the increase in the magnitude of the force that will have to be provided by the bicep muscle to maintain this position?

You should note that the centre of gravity of the barbel lies 0.3 m from the pivot, when measured along a line parallel to the forearm (see Figure 16). (Acceleration due to gravity may be taken as 10 $m \cdot s^{-2}$).

136 Answer

Figure 17 shows an athlete who is holding his lower leg, plus an attached weight, in a stationary position relative to his upper leg.

Figure 17 Lower leg in angular equilibrium.

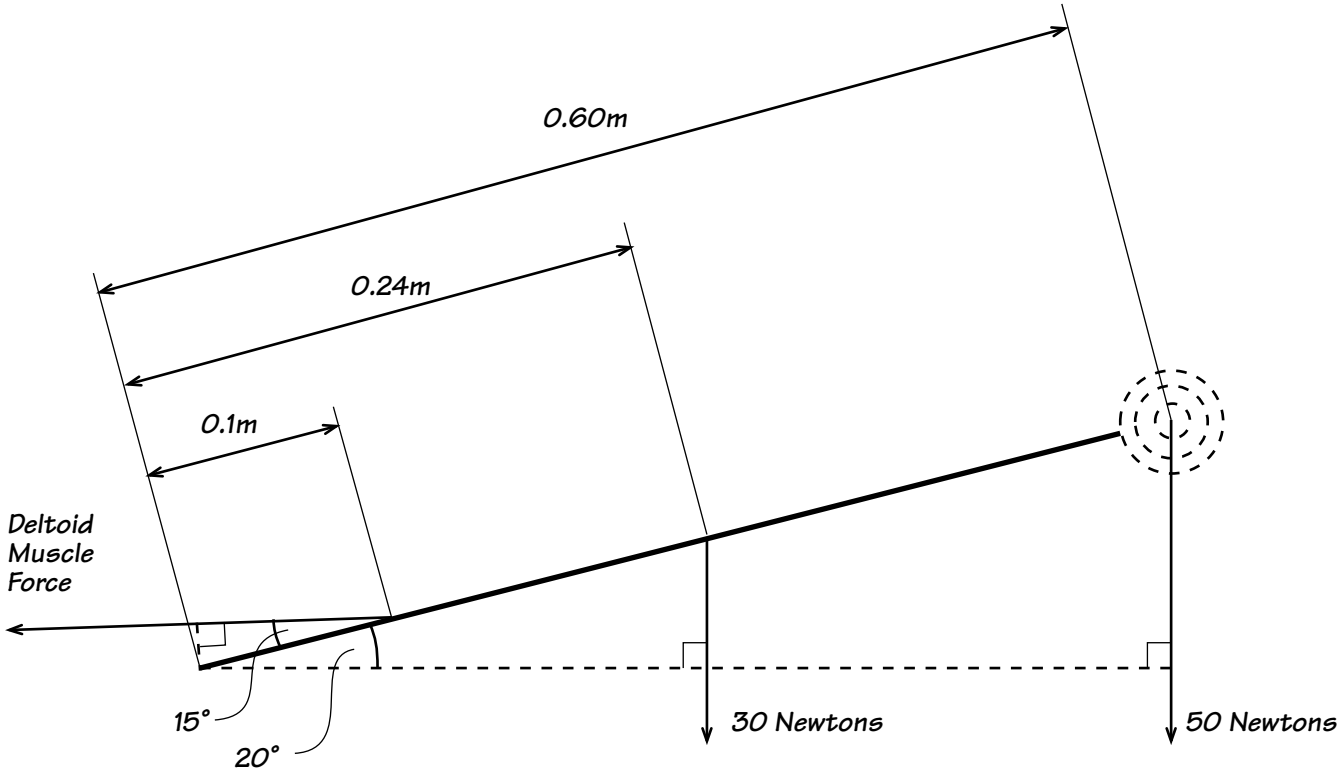


By using the information provided calculate the force that the quadriceps will have to exert in order to maintain this position.

137 Answer

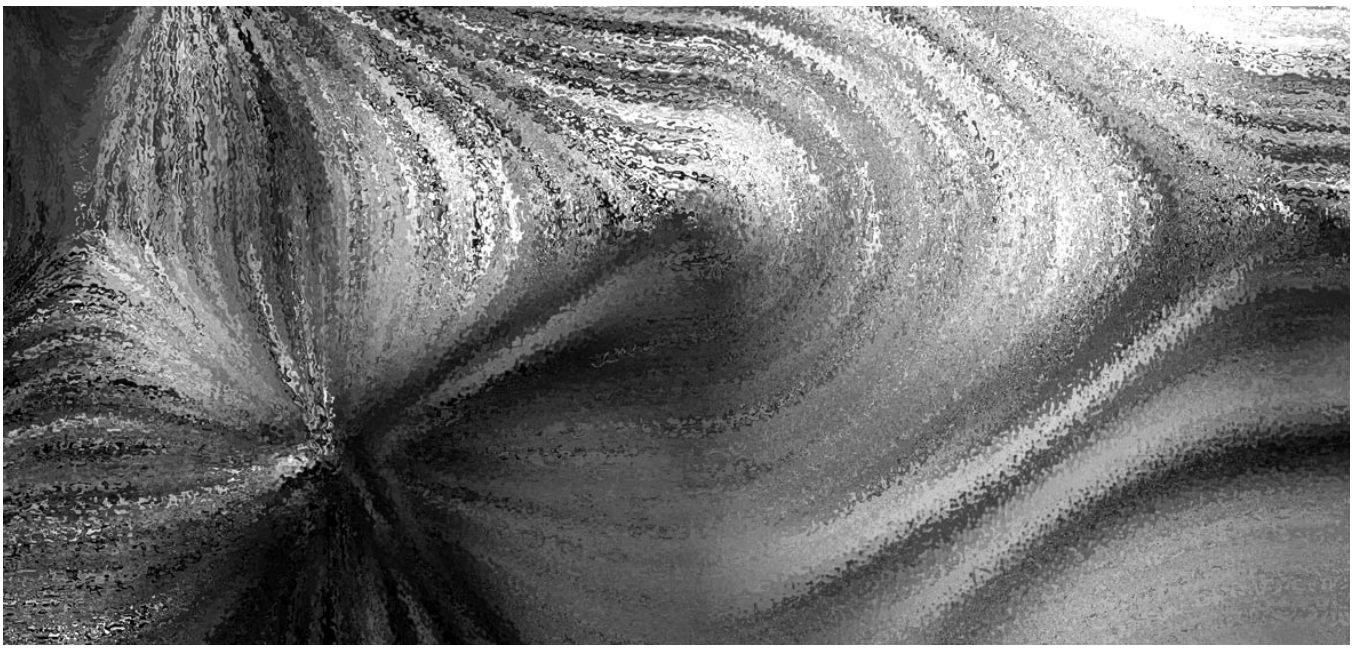
Figure 18 shows the arm of an athlete being held in a stationary position.

Figure 18 The arm in angular equilibrium.



Using the information provided calculate the muscle force that must be exerted by the shoulder abductor muscles (deltoids) in order to maintain the position shown.

ASSIGNMENT ELEVEN
ANGULAR MOMENTUM



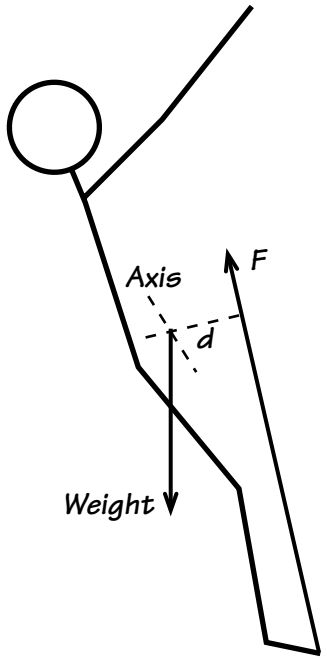
ANGULAR MOMENTUM

The pupose of this investigation is to consider the concepts associated with the generation of angular momentum. In 'Mechanics and Sport Performance' by Peter Walder; Feltham Press it is explained that for situations where a complex sequence of segmental movements are involved in a movement generating rotation, the torque acting on the sports person may be quantified by considering the magnitude, and direction, of the ground reaction force, in relation to the centre of gravity.

138 Answer

The following stages outline the process that may used to calculate angular momentum for events which start from a stationary position. The process requires that the ground reaction forces generated during the event be recorded. This is normally achieved by using a device called a force platform. Also information about the position of the centre of gravity is needed. In the following account, the procedures have been simplified so that the overall process can be appreciated. The event to be investigated is the take off phase of a flic flac which was undertaken from a stationary standing position.

Figure 19 Ground reaction force generating a moment (torque) about an axis passing through the centre of gravity during the take off phase of a flic flac.



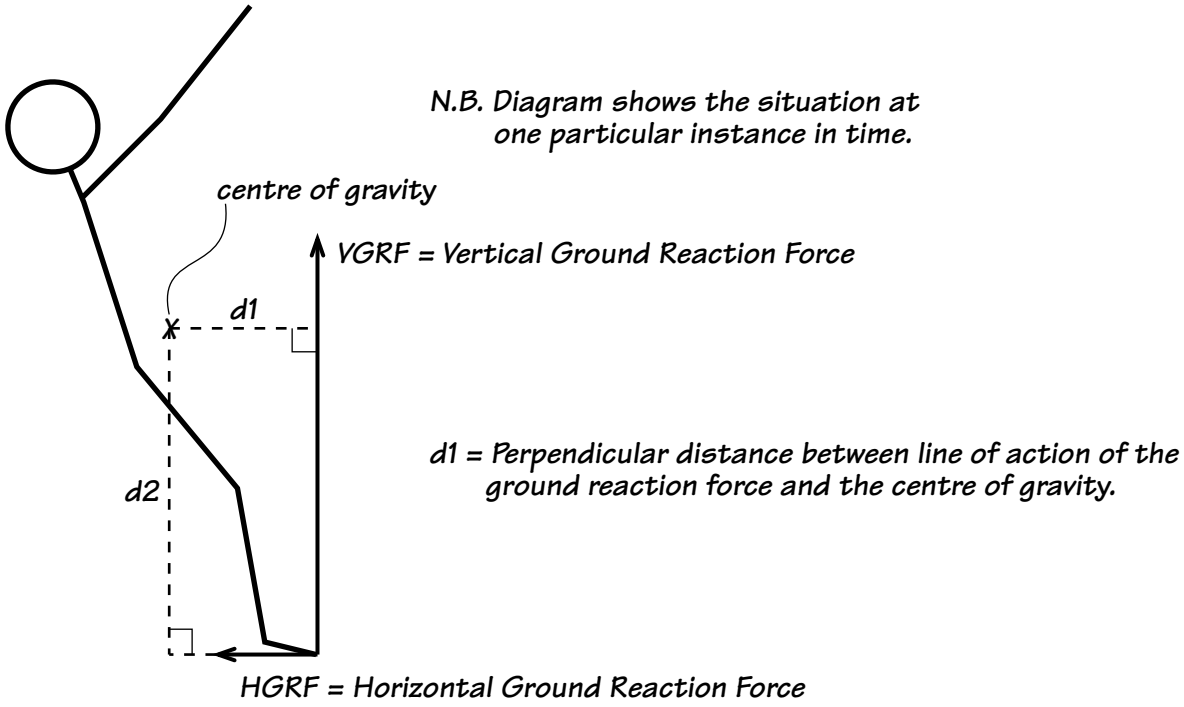
N.B. Diagram shows the situation at one particular instance in time.

F = Ground reaction force

d = Perpendicular distance between line of action of the ground reaction force and the centre of gravity (axis).

The data required for the calculation are, the vertical and horizontal ground reaction forces, and the perpendicular distances from the lines of action of the component ground reaction force.

Figure 20 Component ground reaction forces generating torques about an axis passing through the centre of gravity during the take off phase of a flic flac.


N.B. Diagram shows the situation at one particular instance in time.
centre of gravity
VGRF = Vertical Ground Reaction Force
d1
d1 = Perpendicular distance between line of action of the ground reaction force and the centre of gravity.
d2
HGRF = Horizontal Ground Reaction Force

The force data that are most readily available, are the components of ground reaction force which a force platform can produce. The vertical and horizontal ground reaction force values, which have been sampled every 0.05 second during the take off, are shown in Table 20 in Column 1 and Column 4.

The distances that the forces act from the centre of gravity, are a little more complicated to derive, as centre of pressure (i.e. point of application of force) and centre of gravity position data, need to be utilised. In order to simplify the calculation, the perpendicuar distances from the centre of gravity for the lines of action of the vertical and horizontal forces, have already been worked out, and appear in Table 20 in column 2 and column 5.

Table 20 Data relating to the take off phase of a flic flac undertaken from a stationary standing position.

Col 1 Vertical Force (N)	Col 2 Horizontal Distance (m)	Col 3 Torque (N.m)	Col 4 Horizontal Force (N)	Col 5 Vertical Distance (m)	Col 6 Torque (N.m)	Col 7 Net Torque (N.m)	Col 8 Time (s)
660	0		0.0	1.10			0.00
651	0.010		1.0	1.09			0.05
630	0.012		3.0	1.09			0.10
620	0.012		6.0	1.08			0.15
568	0.025		10.0	1.07			0.20
534	0.056		– 8.0	1.06			0.25
529	0.080		– 19.0	1.05			0.30
607	0.110		– 25.0	1.04			0.35
609	0.130		– 35.0	1.03			0.40
612	0.132		– 37.0	1.02			0.45
666	0.138		– 40.0	1.00			0.50
816	0.142		– 53.0	0.97			0.55
887	0.146		– 79.0	0.96			0.60
912	0.158		– 108.0	0.95			0.65
985	0.168		– 118.0	0.95			0.70
1120	0.179		– 150.0	0.97			0.75
1309	0.219		– 215.0	1.01			0.80
1547	0.240		– 274.0	1.03			0.85
1654	0.284		– 322.0	1.05			0.90
1174	0.300		– 232.0	1.07			0.95
630	0.308		– 100.0	1.08			1.00
0	0.309		0.0	1.08			1.05

First work out the torque generated by the vertical force at each recorded instant, by multiplying the force value by the associated distance value, and record the result in Column 3 of Table 20.

139 Answer

Repeat the process for the horizontal force values and their associated distances for each instant, and record the result in Column 6 of Table 20.

The conventions for the direction of the torque are that anti clockwise torques are regarded as positive, and clockwise torques as negative. In the set of example data, the vertical ground reaction force generates a positive torque throughout the event. The horizontal ground reaction force is defined to be positive when acting on the gymnast in forward direction, and negative when acting backwards (ie in this case the direction of travel). The horizontal ground reaction force generates a positive torque for a short period of time at the start, but for the rest of the event generates a negative torque.

The torques generated by the component ground reaction forces having now been calculated, the net torque now needs to be derived. This is achieved by summing the corresponding torque values generated by the vertical and horizontal ground reaction force.

140 Answer

Complete Table 20 by entering the net torque values in Column 7.

Remember when summing the component torques, to take into account whether they are positive or negative.

141 Answer

Using the Net torque values you have calculated in column 7 and the time values in column 8, plot a torque v time graph (Solutions Figure S28).

Plot time along the horizontal axis using a scale of 1 cm to 0.1 seconds. Plot torque on the vertical axis using a scale of 1 cm to 10 newton metres

142 Answer

Angular impulse causes a change in angular momentum. Angular impulse is defined as 'torque × time'. On the graph this is represented by the area under the curve, and therefore if the area is determined, the associated change in angular momentum can be ascertained. Because the flic flac started from a stationary position, then the change will actually give the angular momentum obtained by the gymnast up to the point of take off.

In order to estimate the area under the curve use a simple square counting technique.

Establish the value of the area of a one centimetre square. If the recommended scales have been used this will be:

10 N·m × 0.1 s = 1.0 N·m·s ($kg.m^2.s^{-1}$).

Count the number of complete centimetre squares, and record the result. It will be helpful to shade the counted squares.

Combine the remaining partial centimetre squares, and estimate the number of complete squares that can be constructed from the parts. Shade the area as the squares are counted so that it is clear that all parts of the area under the curve have been accounted for. Multiply the total number of unit squares by the angular momentum value represented by one square, if the recommended scale values have been used this will give: total number of squares × 1.0 $kg·m^2·s^{-1}$.

In this way calculate the associated change in angular momentum.

Reference.

Kerwin D. (1988) Method for Calculating Angular Momentum. Proceedings of Sports Biomechanics Section, British Association of Sports Sciences.

Figure 21 A series of stick figures representing stages in the take off phase of a vertical jump (Figures shown 1/10 second intervals).

Figure 22 A series of stick figures representing stages in the take off phase of a back flic flac (Figures shown 1/12.5 second intervals).

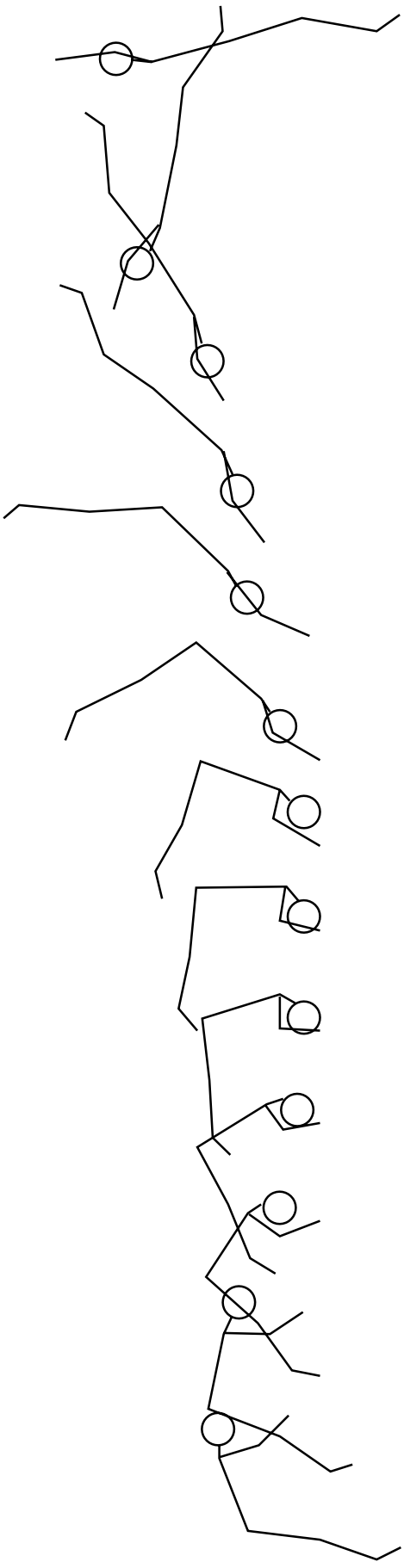


Figure 23 A series of stick figures representing stages in the performance of a head spring (Figures shown 1/12.5 second intervals).

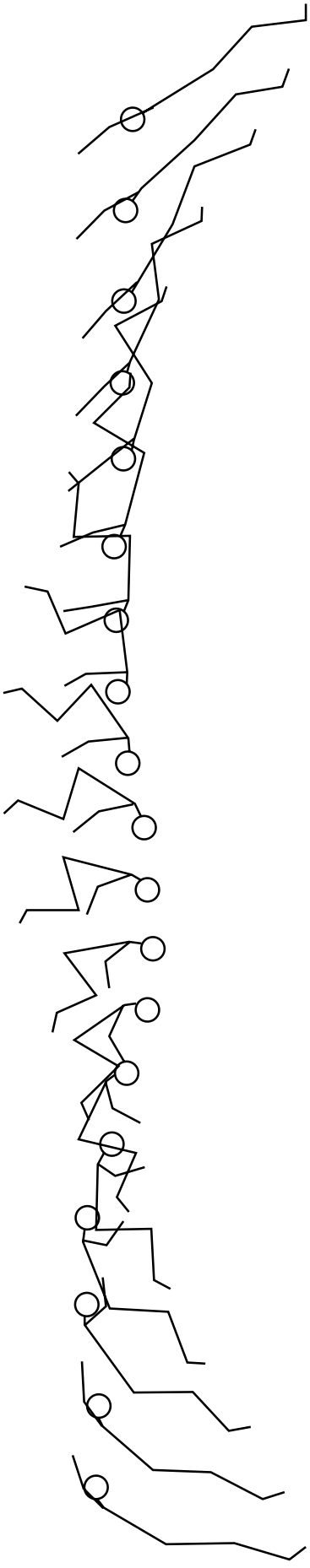


Figure 24 A series of stick figures representing stages in the performance of a front somersault (Figures shown 1/25 second intervals).

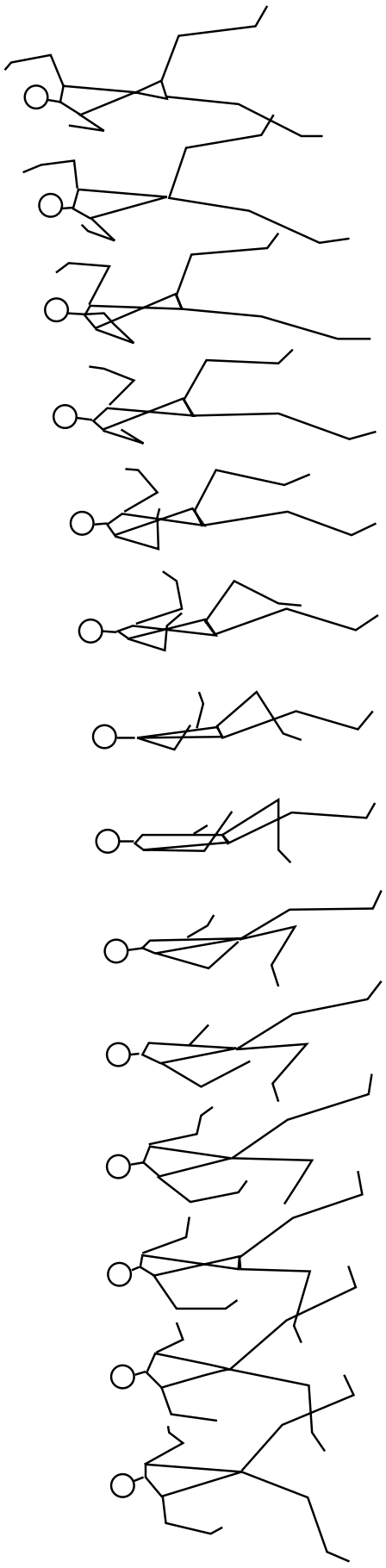
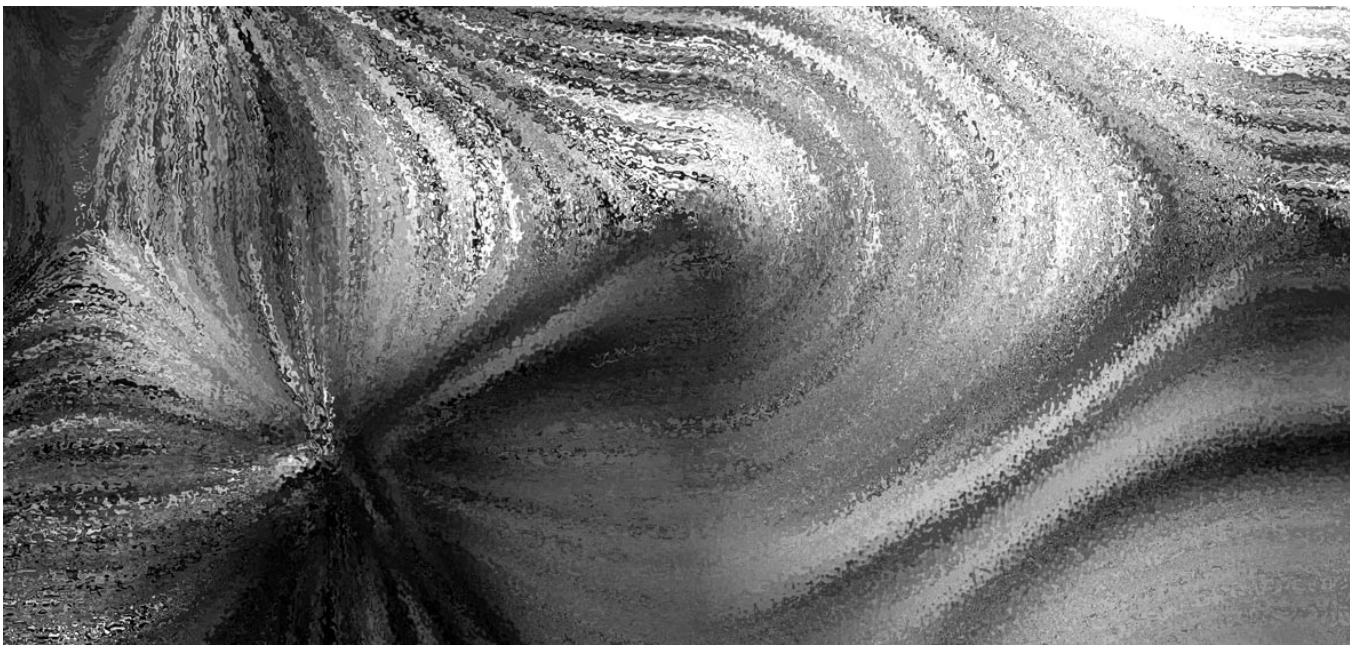


Figure 25 A series of stick figures representing stages in the performance of a longl jump (Figures shown 1/50 second intervals).

SOLUTIONS



Solutions ASSIGNMENT ONE

DISTANCE AND DISPLACEMENT

1 Scale diagram of yachting race not supplied.

2 Displacement of yacht from start to finish = 5.7 km at an angle of 4° (values recorded from direct measurement)

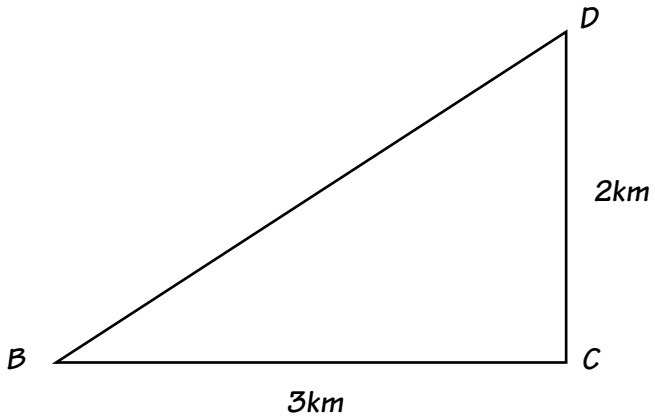
3 Displacements: (values recorded from direct measurement)

- **a** from A to C = 4.2 km at an angle 27°
- **b** from B to D = 3.7 km at an angle of 34°
- **c** from A to D = 5.4 km at an angle of 47°
- **d** from C to E = 2.5 km at an angle of 324°
- **e** from B to E = 5.2 km at an angle of 344°

4 Figure S1: Calculating magnitude value for the vector displacement from B to D by using Pythagoras's theorem.

Calculating magnitude of displacement using Pythagoras's theorem:

$(BD)^2 = (BC)^2 + (CD)^2 = 9 + 4 = 13 = BD = \sqrt{13} = 3.61$ km



5

Calculating direction value for the vector displacement (angle) from B to D using trigonometry:

$$\text{Tan } \theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{2}{3} = 0.666$$

$q = 33.69^{o}$

6

Solution not supplied.

7

Using directly measured values for AE of 5.7 km at an angle of 4°

$$\text{Sin } 4^{\circ} = \frac{\text{distance west}}{5.7}$$

Distance travelled west = 5.7 × 0.0698 = 0.40 km

8

$$\text{Cos } 4^{\circ} = \frac{\text{distance north}}{5.7}$$

Distance travelled north = 5.7 × 0.998 = 5.69 km

9

Displacement from start to take off = 0.10 m (in an upwards direction).

10 Displacement for each time interval as shown in Col. 3 Table **S1**

Table S1 Displacement for each time interval of the centre of gravity of a jumper's body for the take off phase of a vertical jump.

Col 1 Time (s)	Col 2 Position (m)	Col 3 Displacem't (m)
0.00	1.04	
		– 0.01
0.05	1.03	
		– 0.01
0.10	1.02	
		– 0.01
0.15	1.01	
		– 0.01
0.20	1.00	
		– 0.02
0.25	0.98	
		– 0.04
0.30	0.94	
		– 0.06
0.35	0.88	
		– 0.06
0.40	0.82	
		– 0.04
0.45	0.78	
		– 0.04
0.50	0.74	
		– 0.02
0.55	0.72	
		0.00
0.60	0.72	
		0.03
0.65	0.75	
		0.06
0.70	0.81	
		0.11
0.75	0.92	
		0.16
0.80	1.08	
		0.06
0.85	1.14	

11 Total distance travelled from start to take off = 0.74 m.

Solutions ASSIGNMENT TWO

CALCULATING, GRAPHING & INTERPRETING POSITION, VELOCITY & ACCELERATION VALUES.

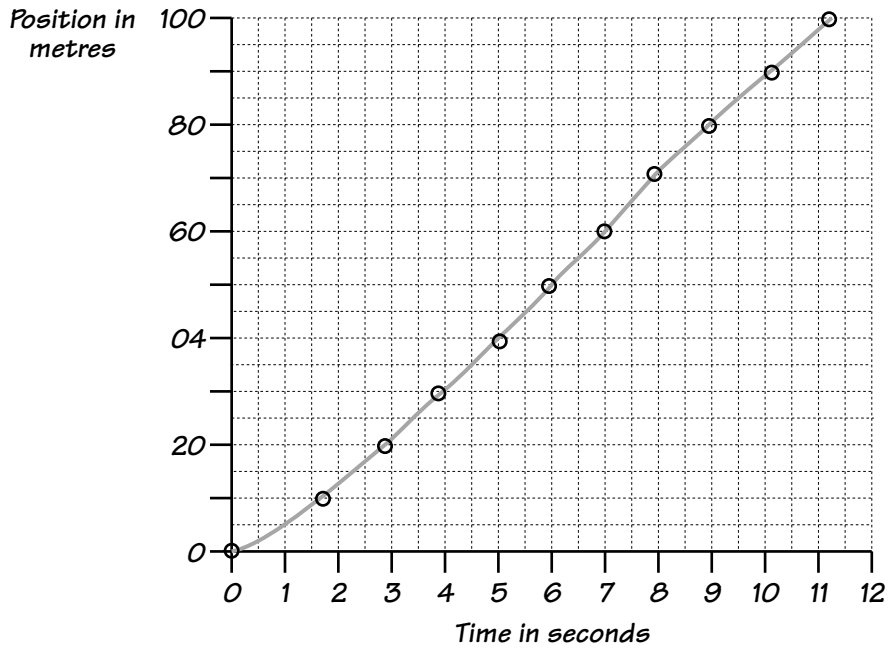
12 & 13 Column 3, Column 4 of Table S2.

Table S2 Variable velocity values calculated from original raw data for 100 m run.

Col 1 Position from start (m)	Col 2 Cumulative Time (s)	Col 3 Time for 10m Intervals (s)	Col 4 Ave' Velocity (m.s-1)
0	0.00		
		1.66	6.02
10	1.66		
		1.18	8.47
20	2.84		
		1.04	9.62
30	3.88		
		1.12	8.93
40	5.00		
		0.95	10.53
50	5.95		
		1.02	9.80
60	6.97		
		0.96	10.42
70	7.93		
		1.04	9.62
80	8.97		
		1.10	9.09
90	10.07		
		1.12	8.93
100	11.19		

14

Figure S2 graph of the original position data of the sprinter v time for a 100m run, with a 'smooth' line drawn through the points.



15, 16 & 17

Column 2, Column 3, Column 4 of **Table S3**.

Table S3 Smoothed position data (read from smoothed original graph at 1 second intervals) and associated velocity calculations

Col 1 Time (s)	Col 2 Position (m)	Col 3 Displacement (m)	Col 4 Av' Velocity ($m \cdot s^{-1}$)
0	0		
		5	5
1	5		
		7	7
2	12		
		9	9
3	21		
		9	9
4	30		
		10	10
5	40		
		10	10
6	50		
		10	10
7	60		
		10	10
8	70		
		10	10
9	80		
		9	9
10	89		
		8	8
11	97		

It should be noted that students undertaking the task will produce a variety of results depending on the success of their smoothing process. As the smoothing is 'by eye' the potential for variation is considerable, and therefore the data are not to be considered as the 'correct' data set.

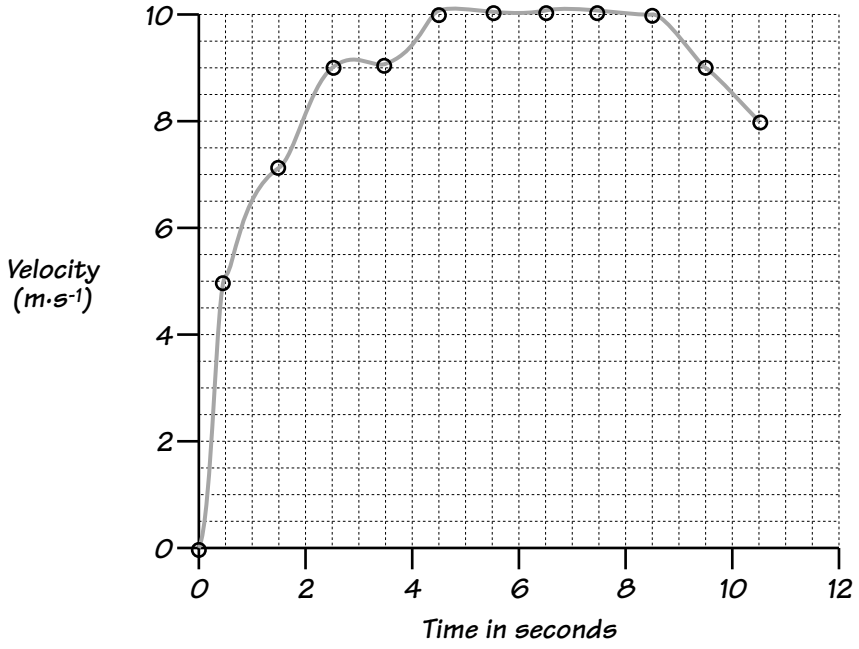
18

Table S3 shows average velocity for individual time intervals. When plotted on a graph the values should be marked at the middle of the time interval for which the average has been calculated, e.g. 0.5, 1.5, 2.5 etc.

If the smoothing of the original position data is effective then the velocity values are likely to show gradual changes as illustrated in **Table S3**, rather than the sudden erratic changes which are produced for calculations on the unsmoothed data.

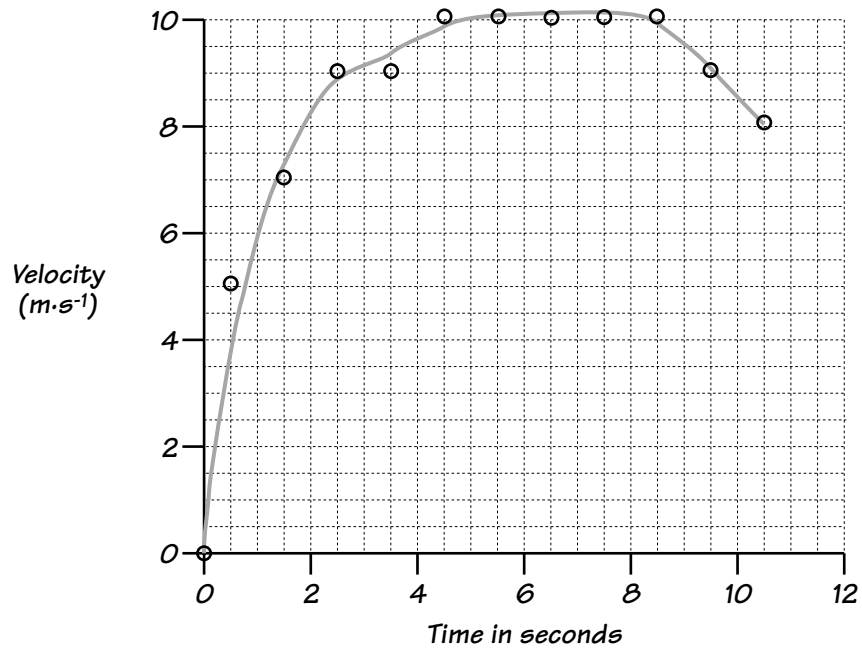
Note that the data would need to be extrapolated if position data for 12 seconds was to be included.

Figure S3 Graph of velocity v time plotted from data in Table S3 without smoothing of curve.



19

Figure S4 Graph of velocity v time plotted from data in Table S3 with smoothing of curve. (Optional on question sheet).



20 & 21 Solutions not supplied

22 Accuracy of diagram; placement of tangent; effects of smoothing on trace; measurement errors; etc.

23, 24 & 25 Column 2, Column 3, Column 4; **Table S4**.

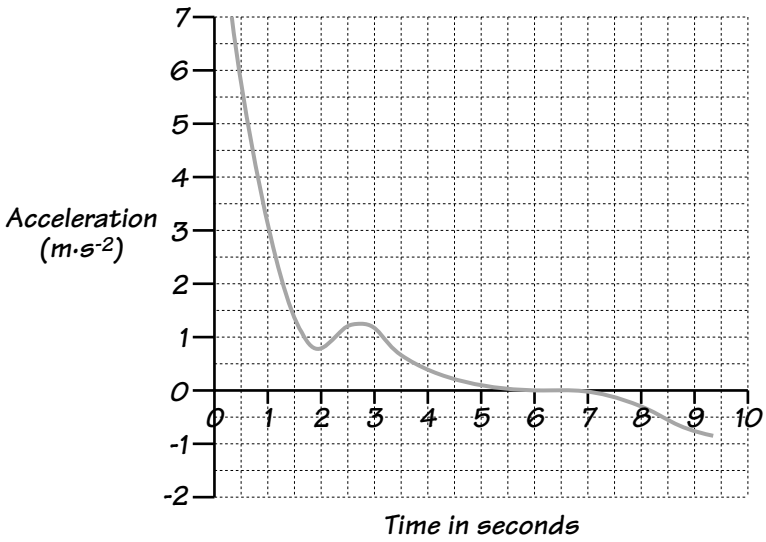
Note that the data in **Table S4** has been read from **Figure S4** which has been smoothed 'by eye'. Considerable variation in the results may be expected depending on the success of the smoothing process

Table S4 Smoothed velocity data read from smoothed velocity curve at 1 second intervals, and associated acceleration calculations. Note that the data would need to be extrapolated for information about 11 and 12 seconds to be included.

	23	**24**	**25**
Col 1 Time (s)	**Col 2 Velocity ($m.s^{-1}$)**	**Col 3 Change in Vel' ($m.s^{-1}$)**	**Col 4 Ave' Accel' ($m.s^{-2}$)**
0	0.00		
		6.00	6.00
1	6.00		
		1.80	1.80
2	7.80		
		1.20	1.20
3	9.00		
		0.65	0.65
4	9.65		
		0.25	0.25
5	9.90		
		0.10	0.10
6	10.00		
		0.00	0.00
7	10.00		
		– 0.10	– 0.10
8	9.90		
		– 0.50	– 0.50
9	9.40		
		– 0.80	– 0.80
10	8.60		

26

Figure S5 Graph of acceleration v time for the 100m sprint from data in Table S4.



As the curve is dependent on data which has been smoothed 'by eye' then variations in results can be expected. It may also be noted that in general it is difficult to obtain accurate acceleration information as the differentiation process tends to magnify the errors in the data.

27

Figure S6 Graph of position v time for the Runner.

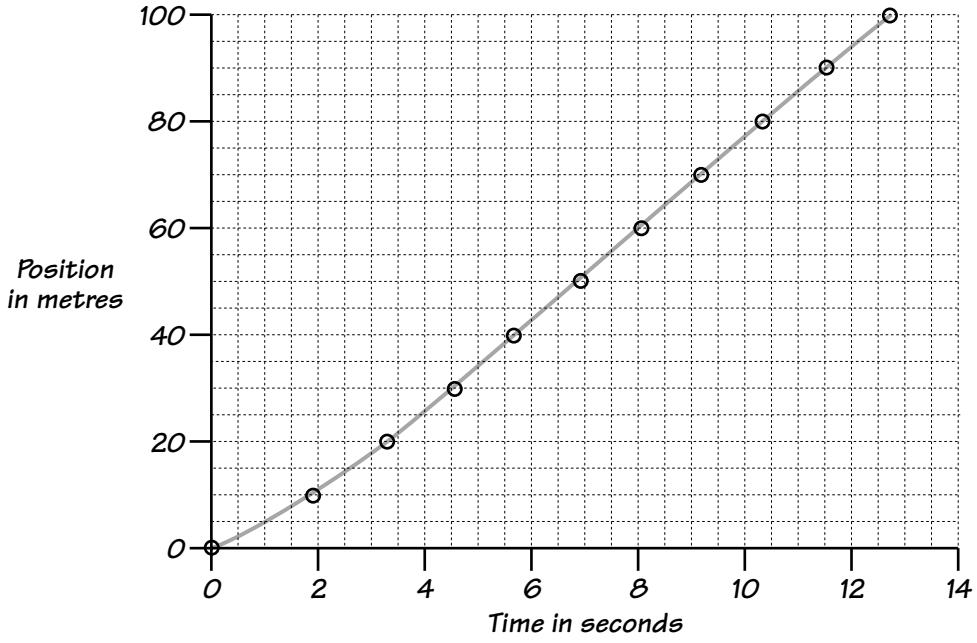
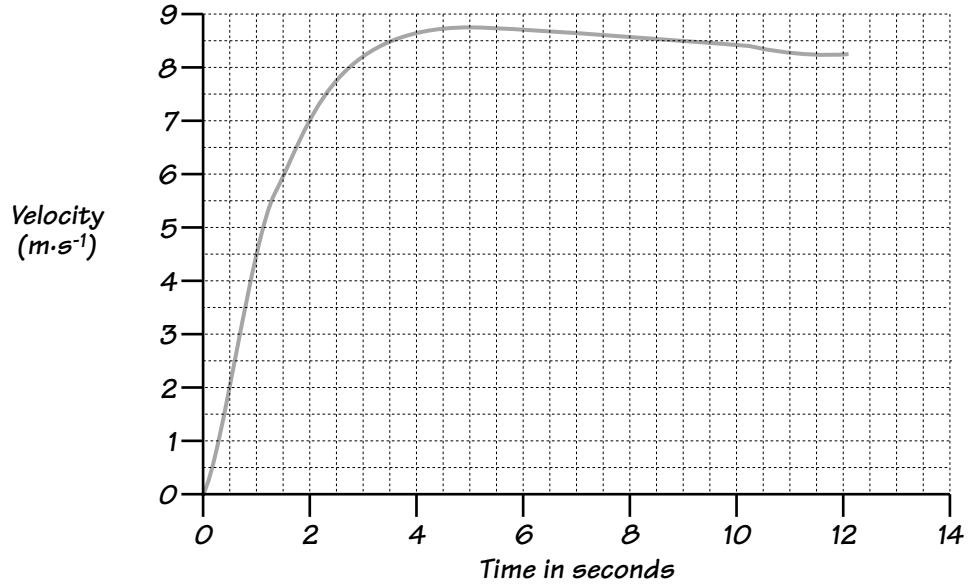


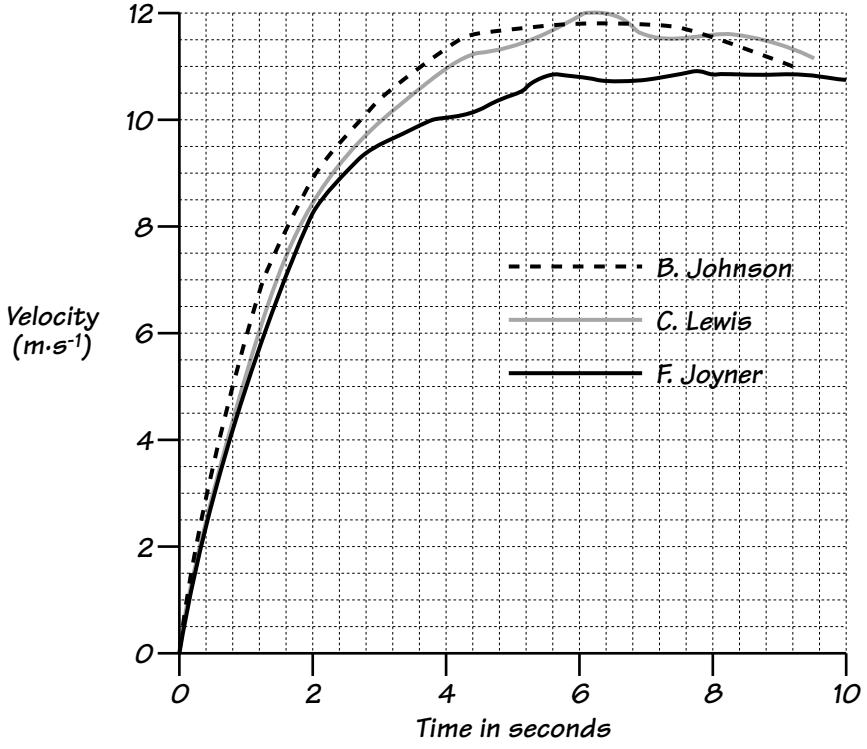
Figure S7 Graph of velocity v time (smoothed) for the Runner in the 100 m Sprint.



28, 29 & 31 Solution not supplied.

30

Figure S8 Graph of velocity v time - B. Johnson, C. Lewis, Ms F. Griffiths-Joyner.



32 The gradient (or slope) of a velocity v time trace provides information about acceleration

Solutions ASSIGNMENT THREE

SPORT RELATED COMPONENTS & RESULTANT VECTORS

33

Vertical velocity component = 5.38 $m \cdot s^{-1}$
Horizontal velocity component = 1.14 $m \cdot s^{-1}$

34

Vertical velocity component = 16.91 $m \cdot s^{-1}$
Horizontal velocity component = 6.16 $m \cdot s^{-1}$

35

Vertical velocity component = 18.47 $m \cdot s^{-1}$
Horizontal velocity component = 23.64 $m \cdot s^{-1}$

36

Speed of release = 15.62 $m \cdot s^{-1}$
Angle of release = 39.81°

37

Speed of release = 9.46 $m \cdot s^{-1}$
Angle of release = 17.86°

38

Vertical velocity component = 19.68 $m \cdot s^{-1}$
Horizontal velocity component = 22.64 $m \cdot s^{-1}$

39

Speed of take off = 7.43 $m \cdot s^{-1}$
Angle of take off = 19.65°

40

Vertical velocity component = 3.95 $m \cdot s^{-1}$
Horizontal velocity component = 1.44 $m \cdot s^{-1}$

41

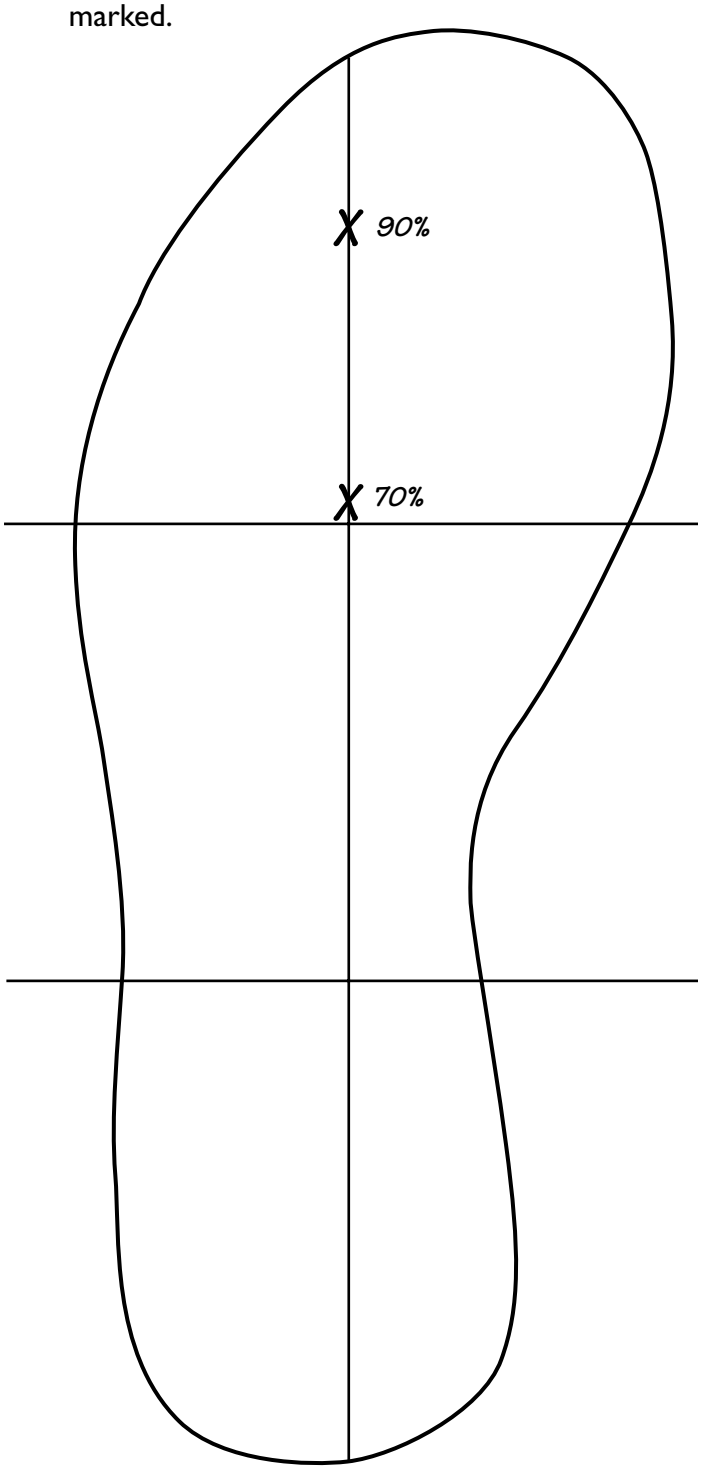
Vertical velocity component = 24.75 $m \cdot s^{-1}$
Horizontal velocity component = 24.75 $m \cdot s^{-1}$

Having completed the above exercises it will be useful to consider the concept of direction. In this section it was noted that for events, such as a vertical jump, which take place along a single line of action but which involve a change in direction, the positive and negative signs can be used to indicate the direction of travel. That is positive velocities are interpreted as describing upward motion and negative velocities as downward motion. It needs to be noted that now it has been observed that a resultant vector can be resolved into orthogonal components, the motion of sports events other than those taking place along a single line of motion can be accurately described by considering their vertical and horizontal component velocities. This last point can be emphasised by explaining that 'speed v time' graphs of an object's motion only portray the magnitude of an object's motion, whereas if a 'vertical velocity v time' graph along with the corresponding 'horizontal velocity v time' graph is used, then the magnitude and direction of the object's motion is specified. By extending the idea to include a description of velocity about a third orthogonal axis, the velocity of an object in three dimensions can be represented.

Solutions ASSIGNMENT FOUR
VECTORS & SPORT

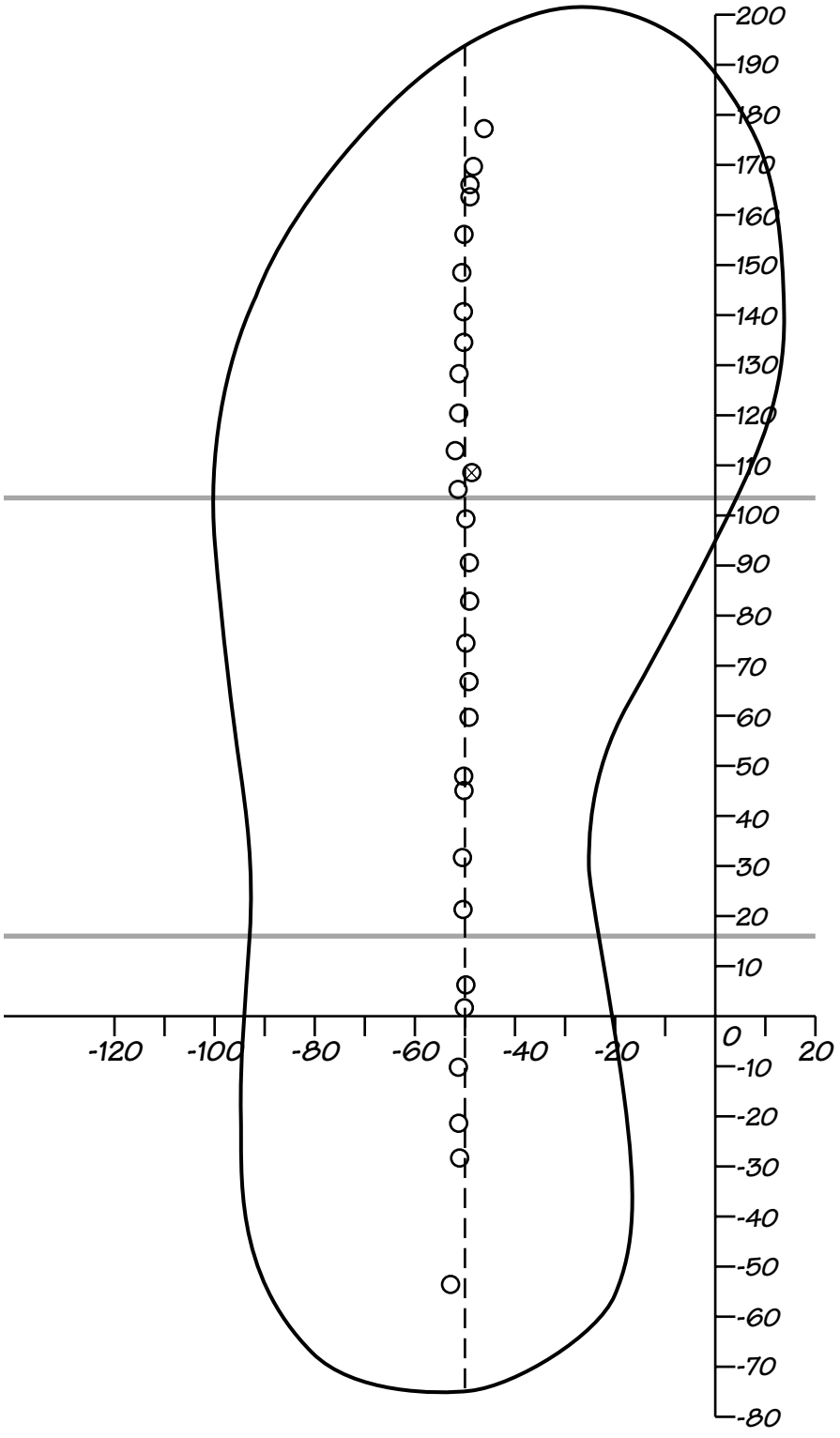
42 Tracing not provided.

43 **Figure S9** Outline of left shoe with 'midline', 70% and 90% points, and 'thirds' marked.



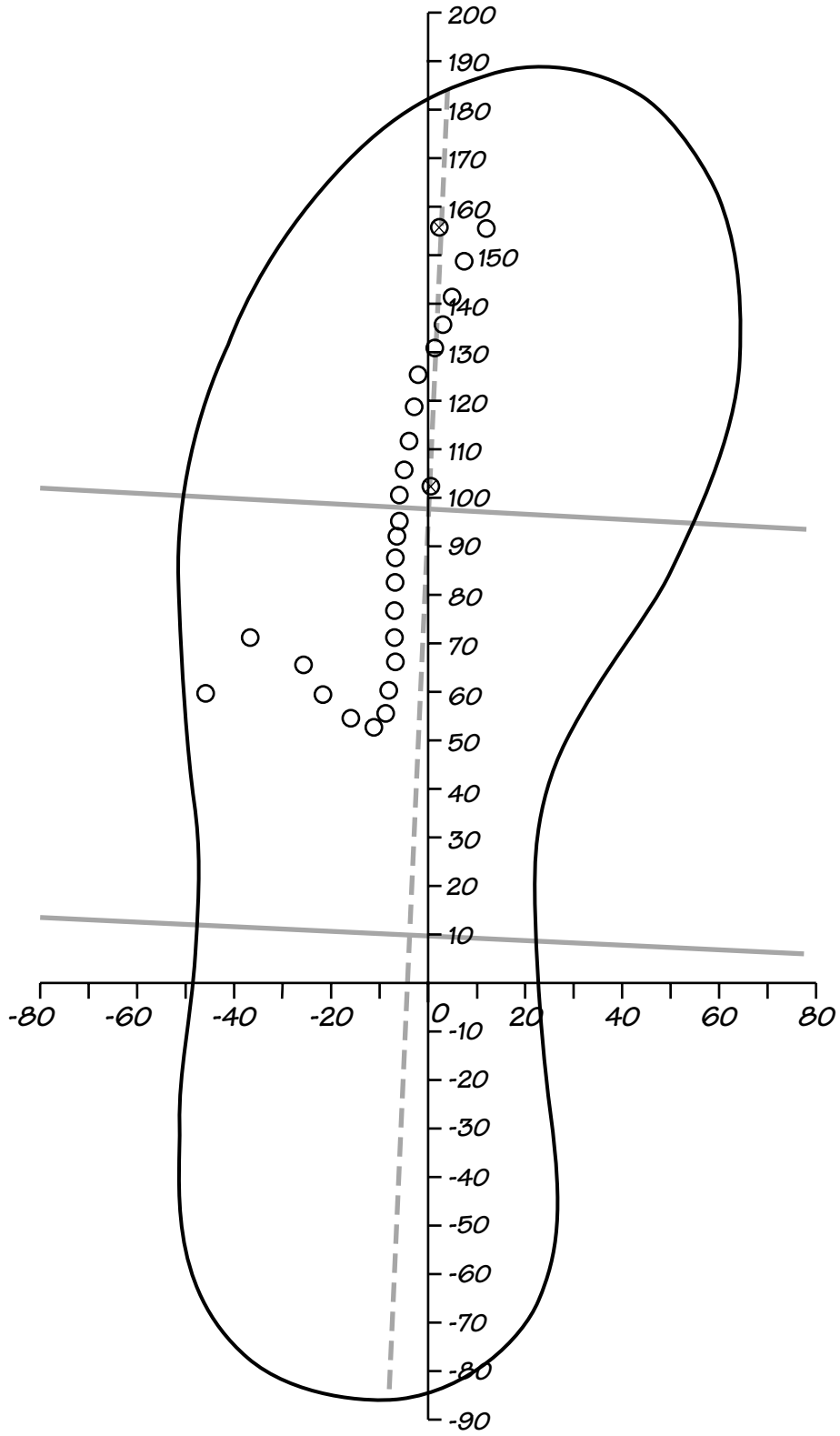
44, 45 & 46 Plotted on Figure S10.

Figure S10 Foot outline and markings for Subject P.



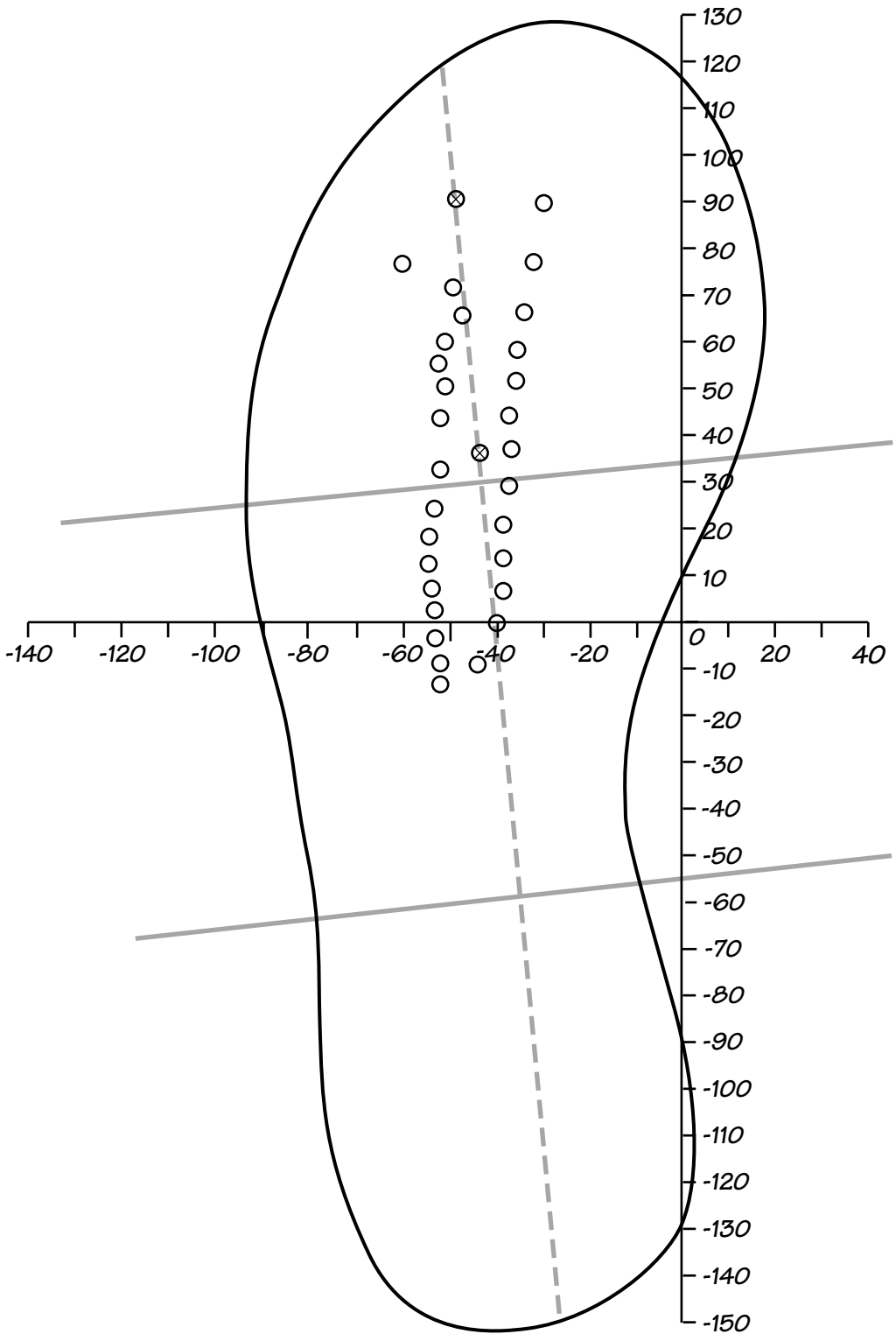
47 Subject **P** would be classified as a rear-foot striker. The trend in pressure pattern for subject **P** suggests that the runner made contact with the rear part of the foot, and then planted the foot with little 'rolling' of the foot.

48 **Figure S11** Foot outline and markings for Subject Q, a mid-foot striker.



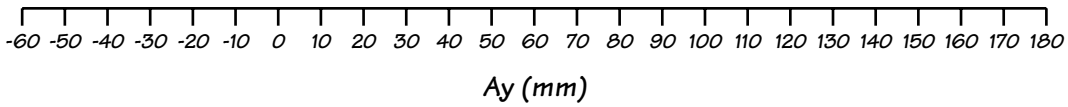
The trend in pressure pattern for subject **Q** suggests that the runner made contact with the ouside part of the left shoe, and the foot then 'rolled' until fully planted. The pressure trace then advances towards the toe as the athlete drives forward.

49 **Figure S12** Foot outline and markings for Subject R, a fore-foot striker.

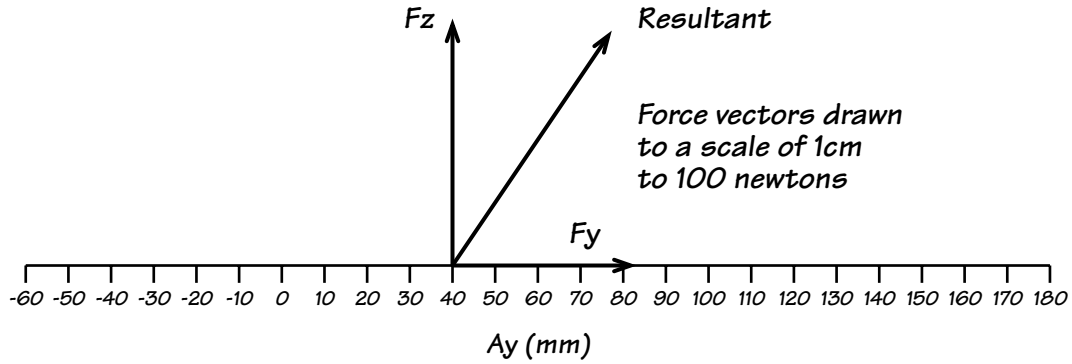


The trend in pressure pattern for subject R suggests that the runner made contact with the front part of the foot. As the foot is planted, this is reflected in a rearward movement of the centre of pressure, followed by an advance forward as the runner drives forward.

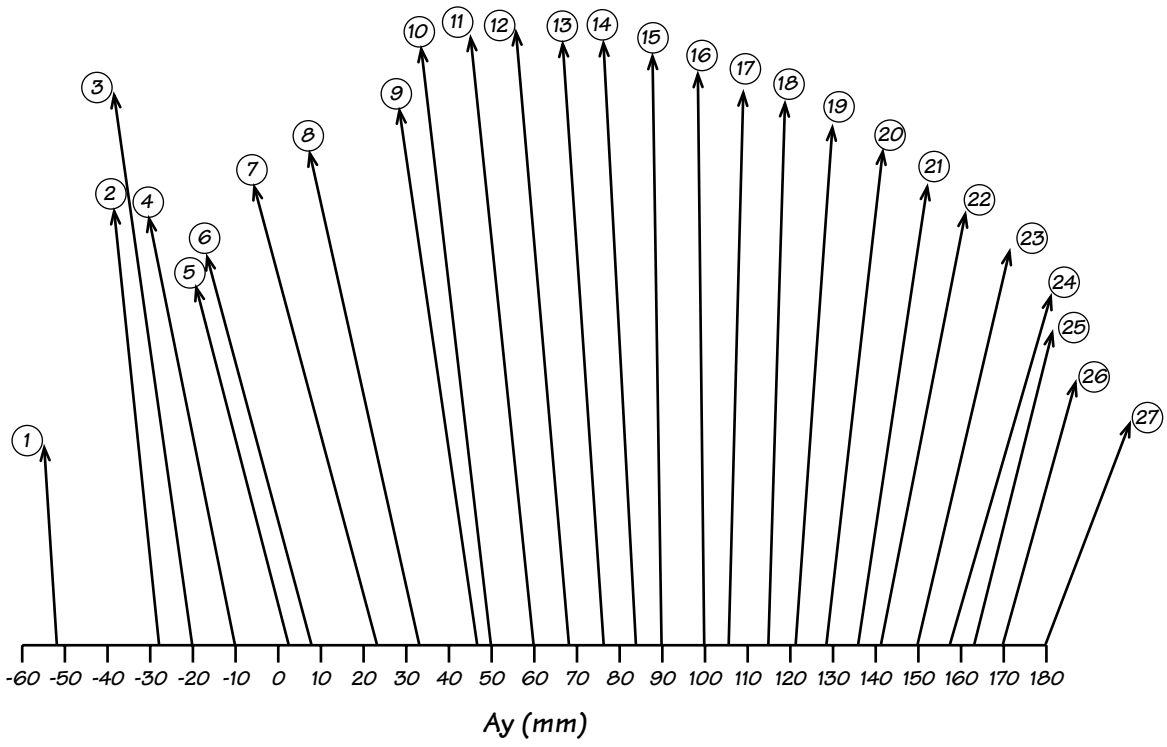
50 **Figure S13** An example of an axis representing Ay Centre of Pressure.



51 **Figure S14** An example of plotting the resultant of the vertical and horizontal ground reaction forces associated with a single (point of application of centre of pressure point Force Vectors superimposed on Ay axis). This diagram shows the principle of superimposing a Force Vector on Ay axis.

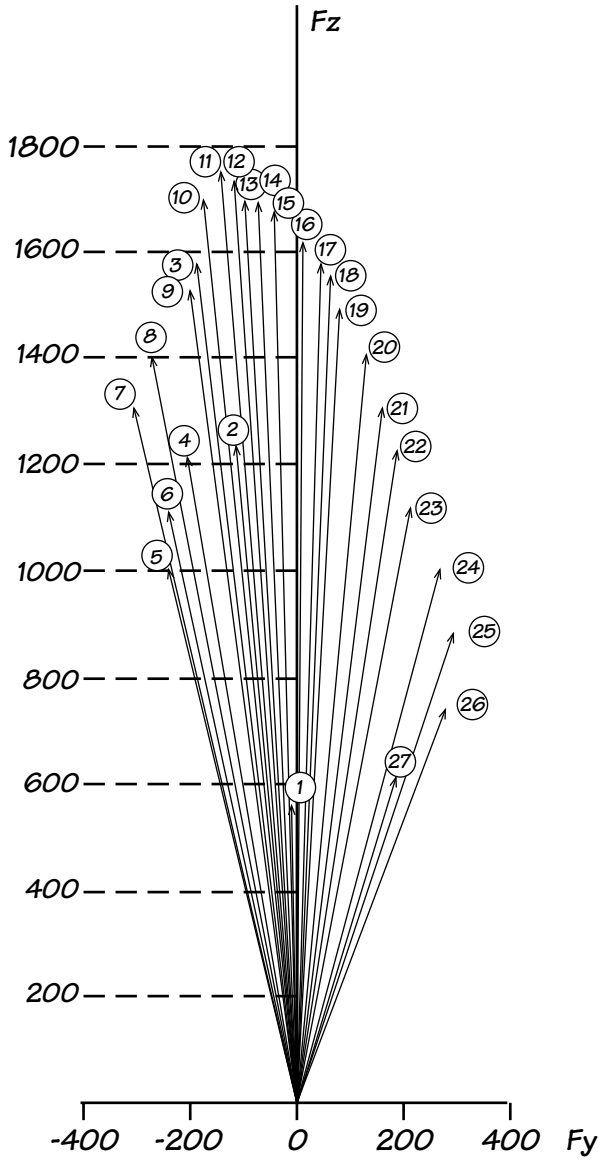


52 **Figure S15** Subject P vectogram (multiple centre of pressure points).



53 During the first half of the foot contact the horizontal ground reaction force is acting backwards on the runner, and therefore according to the specified conventions, the runner will experience a negative acceleration. As the motion of the runner can be considered to be in a straight line with no changes of direction, the runner will slow down during this phase of the footfall. During the second half of the foot contact the ground reaction force acts in a forwards direction on the runner, and therefore the runner will experience a positive acceleration. For this event this will be observed as the runner speeding up.

54 **Figure S16** Simplified vectorgram for Subject A with centre of pressure data omitted, vectors drawn with a common point of application.



55 & 56 Vectorgram, for subject B and C follow the same format.

Solutions ASSIGNMENT FIVE

IMPULSE

57

$F \times t = (m \times v_f) - (m \times v_i)$

F = Force
t = time
m = mass (constant)
v_i = velocity at start of time interval
v_f =velocity at end of time interval

58

When a force is applied over a period of time, the product of the force and the time is termed impulse and causes a change in linear momentum.

$F \times t$ = Impulse
$m \times v_f$ = momentum at end of time interval
$m \times v_i$ = momentum at start of time interval

59

$F \times t = (m \times v_f) - (m \times v_i)$
$100 \times 0.4 = (2 \times v_f) - (2 \times 0)$
$40 = 2 \times v_f$

Therefore at the end of this time period the ball was travelling at:

$v_f = 20$ m·s^{-1}

60

Weight of jumper equals 70 kg × 9.8 m·s^{-2} = 686 N
Constant force of 686 N acts in a downwards direction for a period of 0.63 seconds.

$F \times t = (m \times v_i) - (m \times v_i)$
$-686 \times 0.63 = (70 \times -3.3) - (70 \times v_i)$

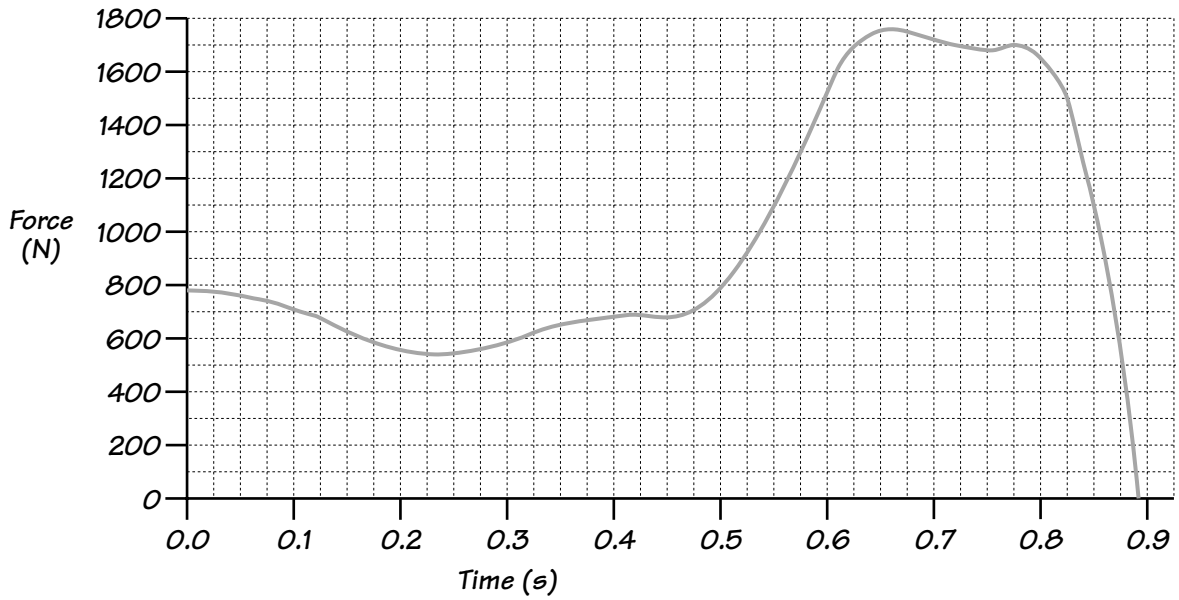
$$\frac{(-686 \times 0.63) - (70 \times -3.3)}{-70} = v_i$$

$$\frac{-201.18}{-70} = v_i$$

Therefore the jumper's vertical velocity at take off = 2.87 m·s^{-1}

61

Figure S17 Graph of vertical ground reaction force v time from data in Table 12 of take off phase of a counter movement based vertical jump.



62 Total impulse generated by the ground reaction force during take off = 860.67 N·s

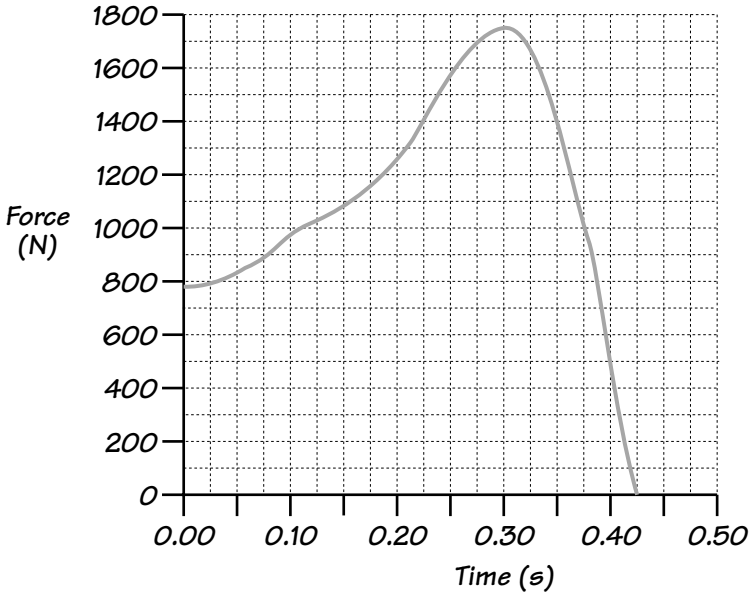
63 The impulse due to gravity = – 676.98 N·s

64 The net impulse acting on the jumper = 183.69 N·s

65 The velocity of the take off of the jumper = 2.34 $m \cdot s^{-1}$
Note: Solutions in **62, 64** and **65** will vary according to estimates made from the graph.

66

Figure S18 Graph of vertical ground reaction force v time during the take off phase of a non counter movement based vertical jump.



Ground reaction impulse = 492.89 N·s
Gravitational impulse = – 323.11 N·s
Net impulse = 169.78 N·s
Velocity at take off = 2.16 $m \cdot s^{-1}$

N.B. Solution may vary according to estimate made from graphs.

67

From these results the jumper using the counter movement appears to have the greater potential to jump high as he has the highest vertical velocity.

68

Other factors which will effect the success of the jump are: body position at take off, body position in air, and timing of body movements. Note that the last two will not affect the height the centre of gravity travels, but may influence the success of the technique in terms of the athlete actually getting part of his/her body high, e.g. a hand in a basketball tip off.

Solutions ASSIGNMENT SIX
CENTRE OF GRAVITY

69 The actual calculation procedures in the first task should enable you to see that a redistribution of the body's mass is reflected in a change in position of the centre of gravity.

70 You should be able to observe a movement of the centre of gravity towards the head as a single arm is raised above the head.

71 A further upward movement corresponds to the second arm being placed overhead.

72 You may note that for those members of the group who appear to have a greater proportion of their body mass located in their arms, a greater movement of the centre of gravity is observed.

73 You may note that experimental error may arise from calibration errors in scales, resolution of measurement available on scales, movement of body mass between segments when adopting different body positions, different overhead arm positions adopted by different subjects, recording and measurement errors. It may be noted that this method is unable to locate the centre of gravity as a point but identifies a line along which its position will be located.

74 You may note that if a vertical jump is performed, where both arms are overhead at take off, then bringing one arm down to the side as the top of the flight is approached, may cause the jumper's body to move upwards relative to the position of the centre of gravity. This would potentially give the jumper an increased reach. It must be noted that the timing of the arm movement would be critical for a successful outcome. It should also be noted that the pathway of the centre of gravity relative to the ground is unaffected by the arm movement i.e. the centre of gravity follows the parabolic path predicted by projectile rules. Hay (1988) has decribed how this principle can be used to explain the phenomena of 'hanging in the air' which is sometimes observed in basketball jump shots and in soccer heading skills.

Ref: Hay J and Reid J *(1988) Anatomy, Mechanics and Human Motion*. Prentice Hall p 192

75 It should be possible to observe a movement of the centre of gravity towards the sprinter's hands as the body moves from the 'on your marks' position to the set position. There will also be an increase in the height of the centre of gravity as the body is raised but the experimental apparatus is unable to detect movements in the vertical plane.

76 It should be possible to note that the position of the centre of gravity lies along a line passing through the base of support. You should be aware that for a stable position to be maintained, the centre of gravity of an object must lie within the supporting base.

77 The procedures in this task allow the calculation of the position of the centre of gravity as a point. The position of the centre of gravity for aerial events identifies the axis of rotation. In the case of the tucked, piked, and hollow somersaults, the position of the body mass relative to the axis of rotation gives an indication of relative moments of inertia for these events. In the case of somersaults, moment of inertia values can be expected to increase in magnitude from the tucked, to piked, to hollow somersault position.

78 Some of the problems associated with this technique, in addition to those already identified in Task 6A, are: 'real' body positions are difficult to duplicate, subjects must maintain position on the board for a considerable length of time, some body positions achieved in a real sports performance cannot be achieved by voluntary muscle actions of subject, distribution of body mass (especially body fluids and viscera) will be differerent in experimental situation, method fails to record a three dimensional position for centre of gravity.

79 For the long jump take off position, there is an advantage to be gained by getting the centre of gravity high, as this will increase the potential relative height of release.

80 A high arched position in the Fosbury flop, which coincides with the peak of flight, will allow a high jumper's body to clear the bar, while the centre of gravity passes much closer to the bar, or even through, or under the bar!

81 The theory of projectiles indicates that the trajectory of the centre of gravity should depict a centre of gravity following a parabolic path.

82 A number of potential sources of error may be identified such as: identification of joint centres and segmental end points; distortions resulting from images copied off a curved screen; inaccuracy of visual comparison between mannikin position and stick figures, assumption of fixed segmental mass in mannikin model; assumption of 'pin' joints of mannikin model.

83 For events with a requirement for balance, the line of gravity should fall within the base of support. Given other factors being equal, events with high centre of gravity positions are potentially less stable than those with low centre of gravity positions.

84 Solution not supplied.

Solutions ASSIGNMENT SEVEN
FORCE & CHANGES IN MOTION

85 Mass = 70 kg Weight = 70 kg × 9.8m·s^{-2} = 686 N

86 **Table S5** with Columns 1-5.

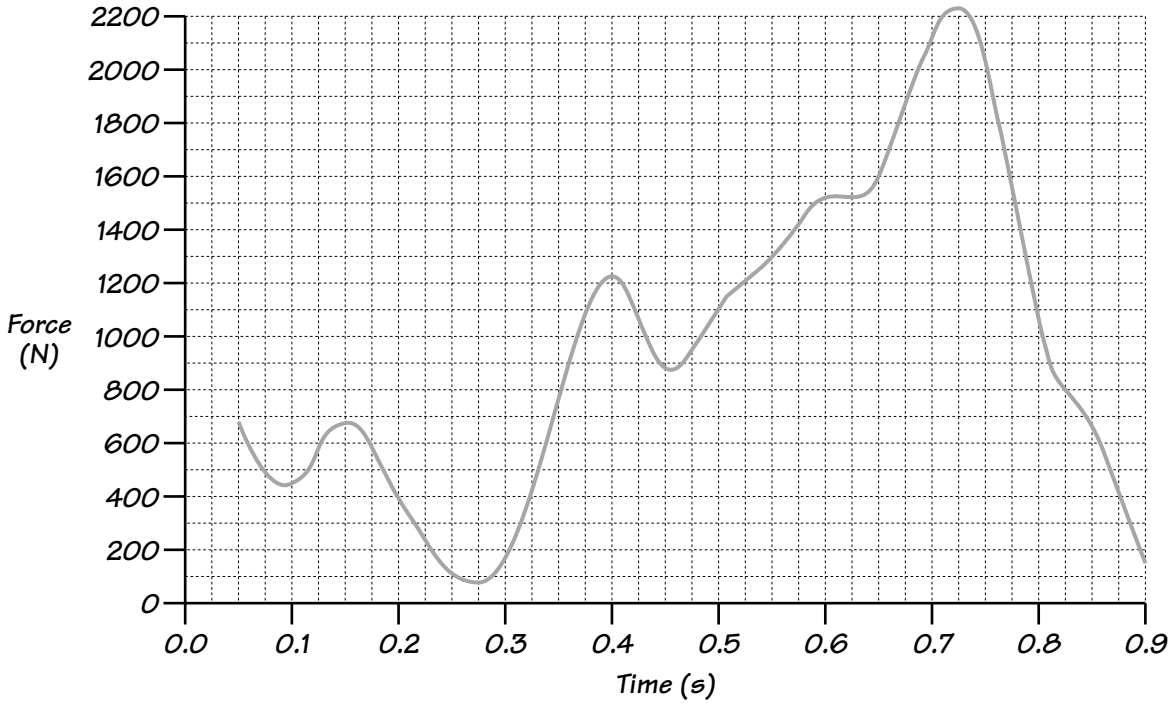
87, 88, 89 & 90 Column 6, Column 7, Column 8, Column 9 of **Table S5**

Table S5 Stages in the calculation of force values from an original set of position and time data.

86					87	88	89	90
Col 1 Time (s)	Col 2 Pos't. (cm)	Col 3 Displ' (cm)	Col 4 Displ' (m)	Col 5 Vel' (m·s^{-1})	Col 6 Change Vel' (m·s^{-1})	Col 7 Ave'Acc' (m·s^{-2})	Col 8 F = ma (N)	Col 9 GRF (N)
0.00	102.00							
		0.00	0.000	0.00				
0.05	102.00				0.00	0.00	0	686
		0.00	0.000	0.00				
0.10	102.00				– 0.20	– 4.00	– 280	406
		– 1.00	– 0.010	– 0.20				
0.15	101.00				0.00	0.00	0	686
		– 1.00	– 0.010	– 0.20				
0.20	100.00				– 0.20	– 4.00	– 280	406
		– 2.00	– 0.020	– 0.40				
0.25	98.00				– 0.40	– 8.00	– 560	126
		– 4.00	– 0.040	– 0.80				
0.30	94.00				– 0.40	– 8.00	– 560	126
		– 6.00	– 0.060	– 1.20				
0.35	88.00				0.00	0.00	0	686
		– 6.00	– 0.060	– 1.20				
0.40	82.00				0.40	8.00	560	1246
		– 4.00	– 0.040	– 0.80				
0.45	78.00				0.10	2.00	140	826
		– 3.50	– 0.035	– 0.70				
0.50	74.50				0.30	6.00	420	1106
		– 2.00	– 0.020	– 0.40				
0.55	72.50				0.40	8.00	560	1246
		0.00	0.000	0.00				
0.60	72.50				0.60	12.00	840	1526
		3.00	0.030	0.60				
0.65	75.50				0.60	12.00	840	1526
		6.00	0.060	1.20				
0.70	81.50				1.00	20.00	1400	2086
		11.00	0.130	2.20				
0.75	92.50				0.40	8.00	560	1246
		13.00	0.120	2.60				
0.80	105.50				– 0.20	– 4.00	– 280	406
		12.00	0.170	2.40				
0.85	117.50							

91

Figure S19 Graph of Vertical Ground Reaction Force during the take off phase of a vertical jump (derived from original position v time data).



Note that original data was taken from film, and that errors in the data collection and processing stages are evident in the results. Some of the variations observed in the acceleration values in the move are not very typical. It should therefore be noted that some caution must be observed when interpreting acceleration and force data which have been derived using the method outlined in the task sheet.

92 & 93

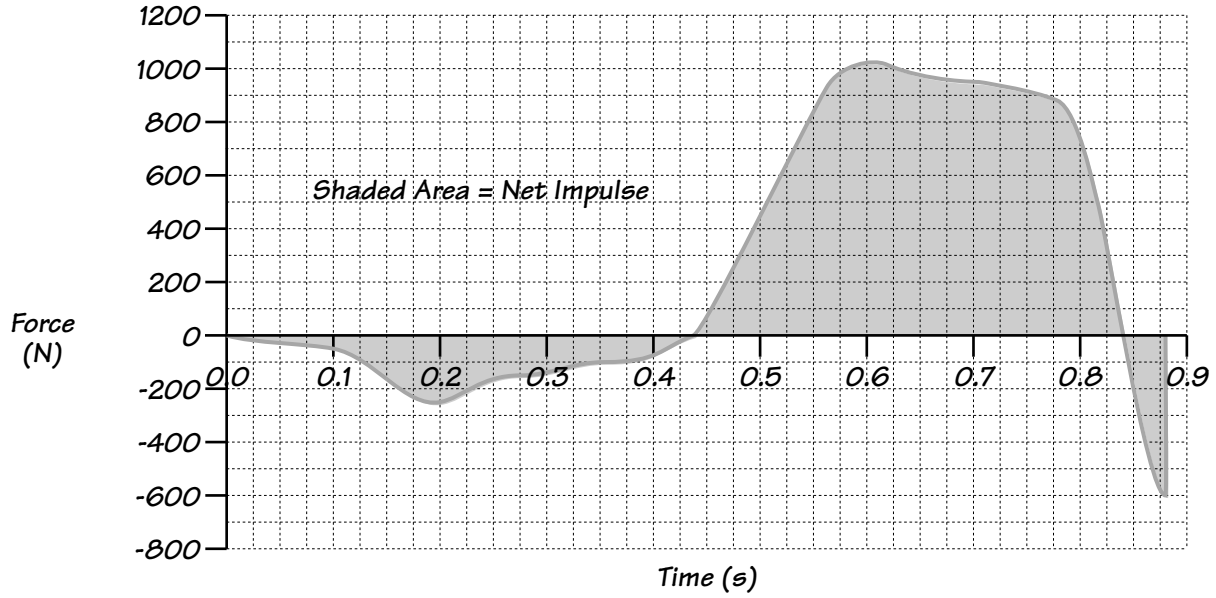
Column 3, Column 4 of **Table S6**.

Table S6 Results for data in Table 15.

		92	93
Col 1 Time (s)	**Col 2 GRF (N)**	**Col 3 Net Force (N)**	**Col 4 Acceleration. ($m \cdot s^{-2}$)**
0.00	686	0	0
0.04	670	– 16	– 0.23
0.08	645	– 41	– 0.59
0.12	627	– 59	– 0.84
0.16	510	– 176	– 2.51
0.20	412	– 274	– 3.91
0.24	510	– 176	– 2.51
0.28	531	– 155	– 2.21
0.32	554	– 132	– 1.89
0.36	598	– 88	– 1.26
0.40	654	– 32	– 0.46
0.44	771	85	1.21
0.48	1022	336	4.80
0.52	1306	620	8.86
0.56	1611	925	13.21
0.60	1704	1018	14.54
0.64	1660	974	13.91
0.68	1638	952	13.60
0.72	1616	930	13.29
0.76	1584	898	12.83
0.80	1420	734	10.49
0.84	700	– 14	– 0.20
0.88	0	– 686	– 9.8

94

Figure S20 Graph of net vertical force acting during the take off phase of a vertical jump.



95 Impulse represented by one unit centimetresquare = 4 N·s.

96 Take off velocity of the jumper = 3.43 $m \cdot s^{-1}$ (Derived from an estimated impulse value using square counting method of 240 N·s).

97 & 98

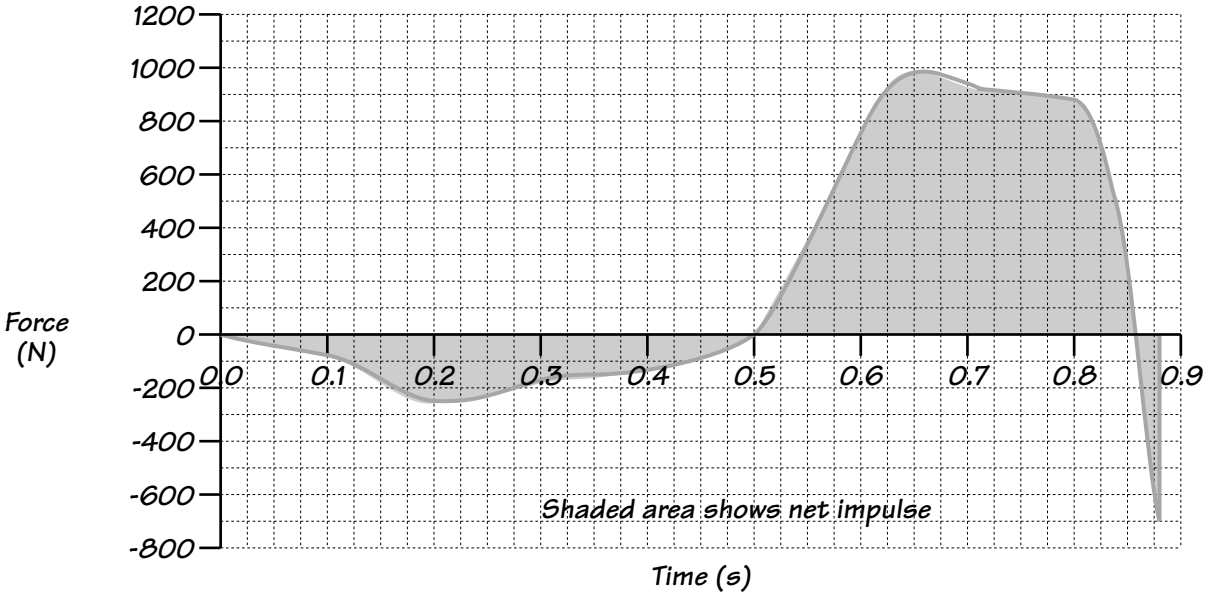
Column 3, Column 4 of **Table S7.**

Table S7 Results for Table 16 (jump 2). Mass = 78.38 kg

		97	98
Col 1 Time (s)	**Col 2 GRF (N)**	**Col 3 Net force (N)**	**Col 4 Acceleration ($m.s^{-2}$)**
0.00	769	0	0
0.04	756	– 13	– 0.17
0.08	708	– 61	– 0.78
0.12	666	– 103	– 1.31
0.16	590	– 179	– 2.28
0.20	539	– 230	– 2.93
0.24	541	– 228	– 2.91
0.28	561	– 208	– 2.65
0.32	593	– 176	– 2.25
0.36	625	– 144	– 1.84
0.40	678	– 91	– 1.16
0.44	690	– 79	– 1.01
0.48	744	– 25	– 0.32
0.52	876	107	1.37
0.56	1193	424	5.41
0.60	1562	793	10.12
0.64	1752	983	12.54
0.68	1728	959	12.24
0.72	1679	910	11.61
0.76	662	893	11.39
0.80	1638	869	11.09
0.84	1315	546	6.97
0.88	0	– 769	– 9.8

99

Figure S21 Graph of Net Vertical Force during the take off phase of a vertical jump.



100 Estimated impulse value calculated using 'square' counting method described in Assignment = 185 N·s. Therefore take off velocity = 2.36 $m \cdot s^{-1}$

101 Therefore jump 1 achieved the higher take off velocity.

102 Estimated maximum downward velocity in jump 1 = – 0.63 $m \cdot s^{-1}$

103 Estimated maximum upward velocity in jump 1 = 3.60 $m \cdot s^{-1}$

104 Estimated maximum downward velocity in jump 2 = – 0.79 $m \cdot s^{-1}$

105 Estimated maximum upward velocity in jump 2 = 2.55 $m \cdot s^{-1}$

Solutions ASSIGNMENT EIGHT
WORK, ENERGY & POWER

106

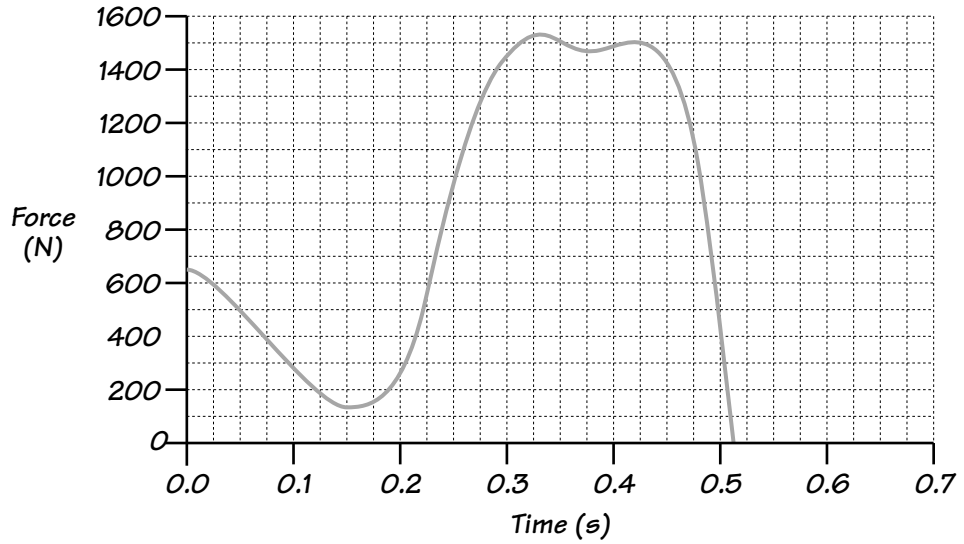
Column 4 **Table S8**.

Table S8 Completed Table 17. Vertical ground reaction force generated, and corresponding vertical velocities of the performer's centre of gravity, during the take-off phase of a vertical jump.

			106
Col 1 Time (s)	**Col 2 Force (N)**	**Col 3 Velocity (m.s-1)**	**Col 4 Power (watts)**
0.0	685	0	0
0.04	585	– 0.04	– 23.40
0.08	468	– 0.058	– 27.14
0.12	329	– 0.197	– 64.81
0.16	207	– 0.423	– 87.56
0.20	153	– 0.705	– 107.87
0.24	173	– 0.997	– 172.48
0.28	363	– 1.231	– 446.85
0.32	905	– 1.221	– 1105.00
0.36	1162	– 0.981	– 1139.92
0.40	1496	– 0.452	– 676.19
0.44	1540	0.132	203.28
0.48	1478	0.707	1044.95
0.52	1467	1.247	1829.35
0.56	1501	1.808	2713.81
0.60	1435	2.356	3380.86
0.64	1142	2.810	3209.02
0.68	0	2.781	0

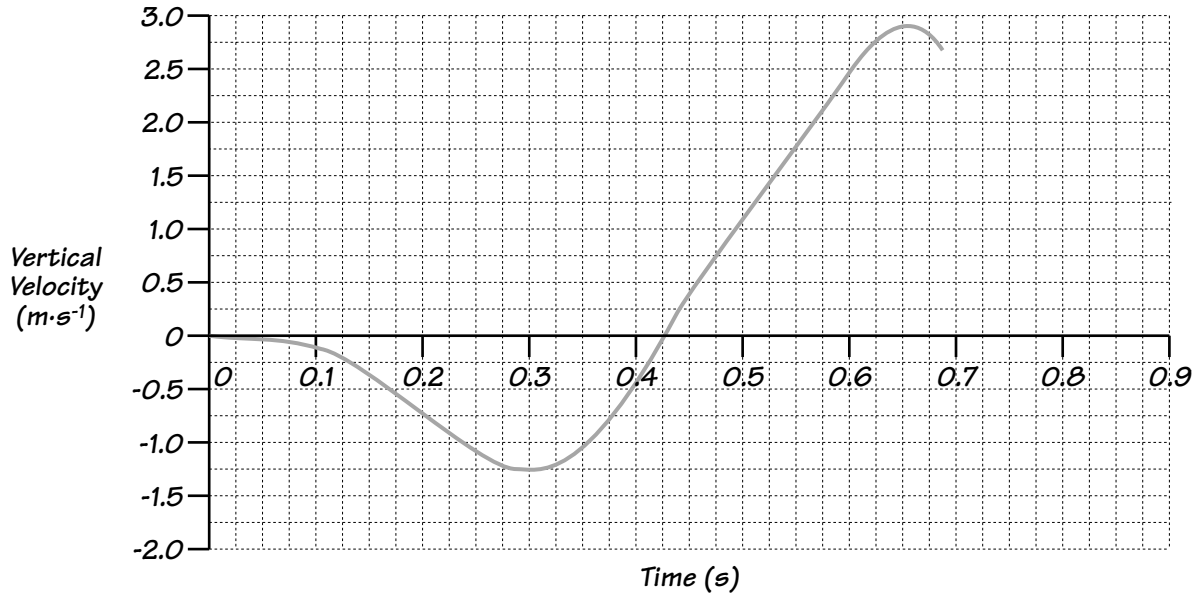
107

Figure S22 Graph of vertical ground reaction force v time during the take off phase of a vertical jump.



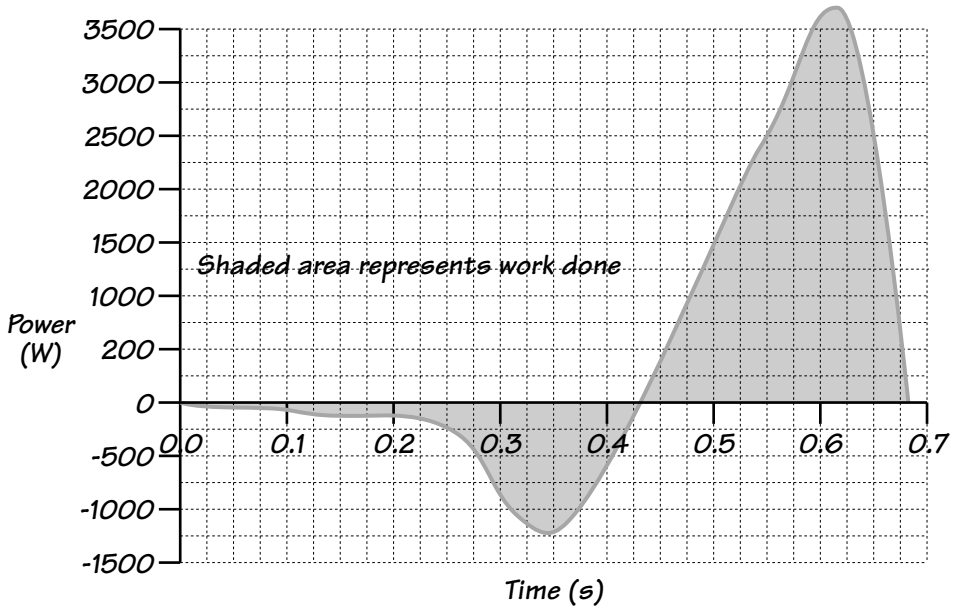
108

Figure S23 Graph of vertical velocity v time during the take off phase of a vertical jump.



109

Figure S24 Graph of power v time during the take off phase of a vertical jump.



110

Negative Work = – 144 joules

(estimated using square counting method).

111

Positive Work = 512 joules

(estimated using square counting method).

112

Total amount of work done during the take off = 368 joules

Solutions ASSIGNMENT NINE

CALCULATING ANGULAR DESCRIPTORS OF SPORTS MOVEMENTS

113 ,114 & 115

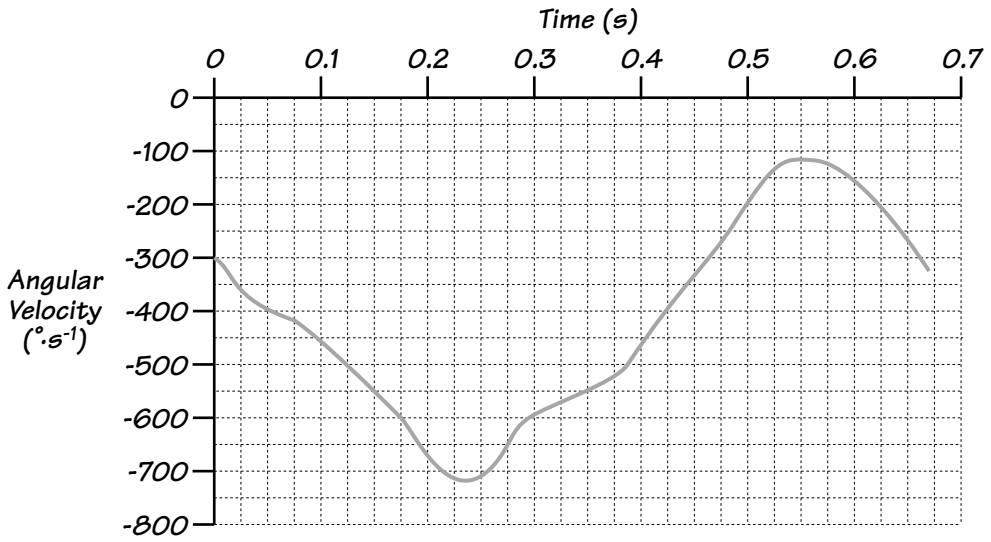
Column 2, Column 3, Column 4 of **Table S9**

Table S9 Data for the trunk segment of the gymnast relative to the reference axis. Table 18 performing a forward somersault off a springboard

	113	114	115
Col 1 Time (s)	**Col 2 Angular Pos' (degrees)**	**Col 3 Angular Displ' (degrees)**	**Col 4 Angular vel. ($deg \cdot s^{-1}$)**
0.00	327		
0.04	317	– 10	– 250
0.08	300	– 17	– 425
0.12	285	– 15	– 375
0.16	264	– 21	– 525
0.20	243	– 21	– 525
0.24	217	– 26	– 650
0.28	187	– 30	– 750
0.32	162	– 25	– 625
0.36	140	– 22	– 550
0.40	118	– 22	– 550
0.44	97	– 21	– 525
0.48	86	– 11	– 275
0.52	71	– 15	– 375
0.56	67	– 4	– 100
0.60	62	– 5	– 125
0.64	55	– 7	– 175
0.68	46	– 9	– 225
0.72	32	– 14	– 350

116

Figure S25 Graph of angular velocity of trunk segment v time during a front somersault.



117

It is important to note that the theoretical shape of the angular velocity trace for the whole body is not observed in the actual trace obtained for the trunk segment*. This serves to emphasise the caution that must be placed on using the angular velocity of an individual segment to represent the angular velocity of the body as a whole.

* Also note that the angular velocity trace shown in **Figure S25** assumes clockwise rotation as being in the negative 'direction', and therefore for the set of data provided, the angular velocity values maintain a negative value. When comparing the trace with the theoretical whole body angular velocity trace it will therefore be easier to consider the changes in angular velocity without reference to sign, i.e. imagine the trunk angular velocity trace to be reflected about the x axis.

The results from this task can be expected to vary considerably depending on the accuracy of original measurements. As indicated in the questions, using the trunk segment as representative of whole body angular motion, has its problems, and therefore care must be taken not to make too much of the results in terms of being representative of whole body angular motion.

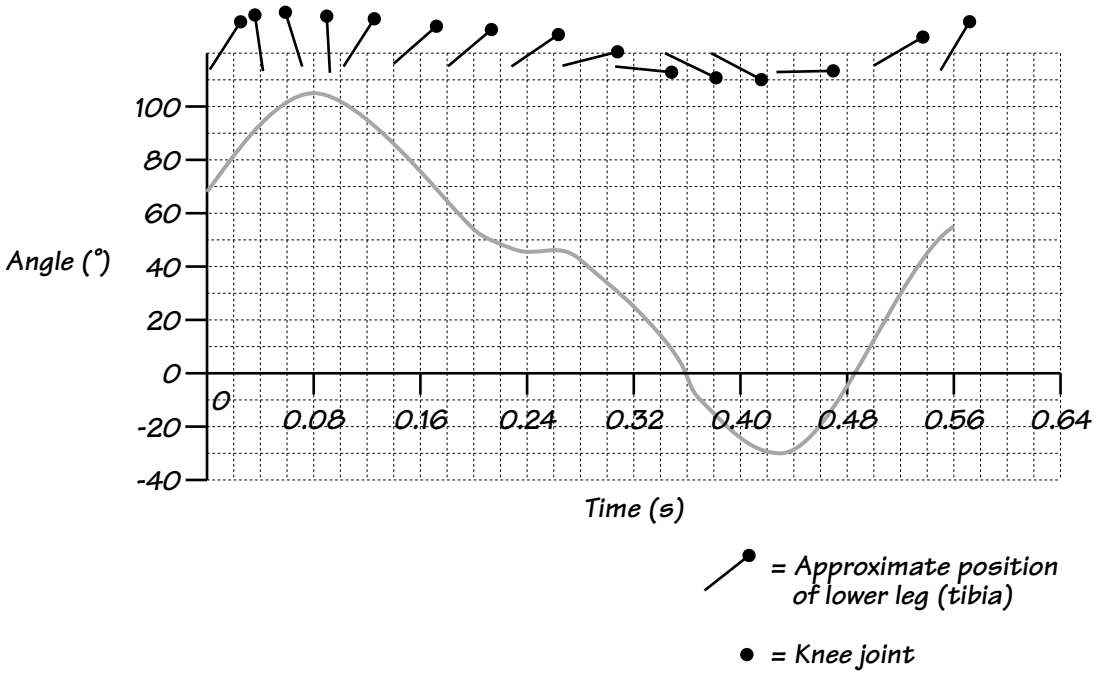
118 & 119

Column 3, Column 4 of **Table S10**.

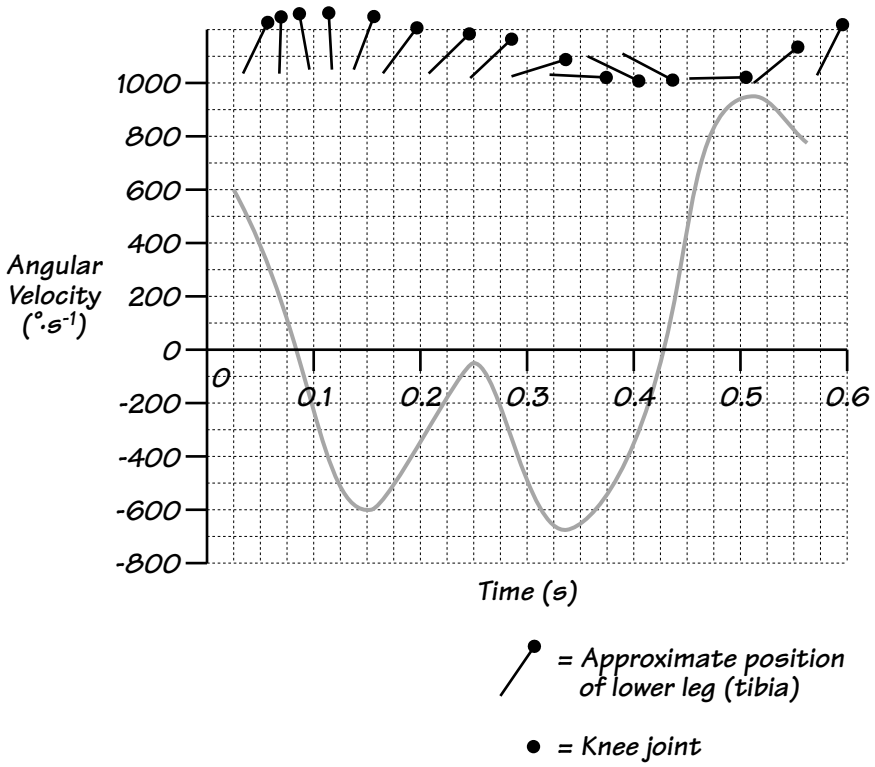
Table S10 Stages in calculating angular velocity from the original angular position data in Table 18.

		118	119
Col 1 Frame	**Col 2 Angle (deg)**	**Col 3 Angular Displ' (deg)**	**Col 4 Angular Velocity ($deg \cdot s^{-1}$)**
1	65.8		
		26.4	660.0
3	92.2		
		11.4	285.0
5	103.6		
		– 8.0	– 200.0
7	95.6		
		– 23.5	– 587.5
9	72.1		
		– 18.3	– 457.5
11	53.8		
		– 9.0	– 225.0
13	44.8		
		– 2.5	– 62.5
15	42.3		
		– 20.0	– 500
17	22.3		
		– 25.8	– 645.0
19	– 3.5		
		– 19.7	– 492.5
21	– 23.2		
		– 4.4	– 110.0
23	– 27.6		
		25.2	630.0
25	– 2.4		
		36.7	917.5
27	34.3		
		30.6	765.0
29	64.9		

120 **Figure S26** Graph of angle v time (lower leg).From data in Table S10.



121 **Figure S27** Graph of angular velocity v time (lower leg).



122 & 123 Solution not supplied.

There are no specific solutions for this task. The angle measurement conventions being used should be stated.

Solutions ASSIGNMENT TEN
MOMENTS/TORQUES

In all solutions anticlockwise torques are treated as positive and clockwise torques as negative.

124 Size of the turning effect (torque) = 87 N·m

125 Moment of force (torque) acting at the instant shown = – 490 N·m

126 Greatest torque in direction of swing experienced on downward path when body is parallel to the floor.

127 Greatest torque acting against direction of swing experienced on upward path when body is parallel to the floor

128 Zero torque is experienced when athlete's body is directly below or directly above the bar.

129 Torque being generated by the ground reaction force = – 55 N·m

130

Horizontal component of the ground reaction force
= 1000 N × Cos 70° (using trig')

Horizontal component of the ground reaction force = 342.0 N

Vertical component of the ground reaction force
= 1000 N × Sin 70° (using trig')

Vertical component of the ground reaction force = 939.7 N

Magnitude of torque generated by vertical component about centre of gravity
= 939.7 N × (0.45 – 0.1) m
= 939.7 N × 0.35 m

Torque generated by vertical component about centre of gravity
= – 328.9 N·m (clockwise)

Magnitude of torque generated by
horizontal component about centre of gravity
= 342.0 N × 0.8 m

Torque generated by horizontal component about centre of gravity
= 273.6 N·m (anti clockwise)

131

Net Torque = – 328.9 N·m + 273.6 N·m = – 55.3 N·m

132

Torque generated by weight of arm = 15 N × 0.15 m = – 2.25 N·m

As arm is in static equilibrium then bicep must be generating a torque of 2.25 N·m

133

As torque generated by biceps is equal to 2.25 N·m then:

2.25 N·m = 0.03 m × F

Therefore force (F) being generated by biceps = 75 N

134

Moment arm of weight force = 0.15 m × Cos 20° = 0.141 m

Torque generated by weight of forearm = 15 N × 0.141 m = – 2.115 N·m

As arm is in static angular equilibrium torque generated by bicep must be equal to 2.115 N·m

Therefore 2.115 N·m = 0.04 × F

Force (F) generated by bicep = 52.9 N

135

Moment arm for barbel = 0.30 m × Cos 20° = 0.282

Torque generated by weight of barbel = 50 N × 0.282 m = – 14.1 N·m

Total clockwise torque = – 2.115 N·m + – 14.1 N·m = – 16. 215 N·m

As arm is in static angular equilibrium, torque generated by bicep must be equal to 16.215 N·m

Therefore 16.215 N·m = 0.04 m × F

Force (F) generated by bicep = 405.38 N

Increase in force generated by bicep = 405.38N – 52.9N = 352.48N

136

Moment arm for lower leg weight = 0.14 m × Cos 47° = 0.095m

Moment arm for barbell weight = 0.30 m × Cos 47° = 0.205 m

Moment arm for quadriceps = 0.05 m × Sin 15° = 0.013 m

Torque generated by weight of lower leg = 0.095 m × 80 N = – 7.6 N·m

Torque generated by weight of barbel = 0.205 m × 100 N = – 20.5 N·m

Total torque acting in a clockwise direction = – 28.1 N·m

As lower leg is in static angular equilibrium, then quadriceps must generate a torque equal to 28.1 N·m.

Therefore 28.1 N.m = F × 0.013 m

Quadriceps force (F) = 2161.538 N

137

Moment arm of weight of arm = 0.24 m × Cos 20° = 0.226 m

Moment arm of barbel = 0.60 m × Cos 20° = 0.564 m

Moment arm of deltoid = 0.1 m × Sin 15° = 0.0259 m

Torque generated by weight of arm = 30 N × 0.226 m = – 6.78 N·m

Torque generated by weight of barbel = 50 N × 0.564 m = – 28.2 N·m

Net clockwise torque = – 34.98 N·m

As arm is in static angular equilibrium then deltoid must generate a torque equal to 34.98 N·m.

Therefore 34.98 N·m = F × 0.0259 m

Deltoid force (F) = 1350 N

Solutions ASSIGNMENT ELEVEN
ANGULAR MOMENTUM

138, 139 & 140 Column 3, Column 6, Column 7 of **Table 20** on page 76.

Table S11 Solutions to calculations.

		138			139	140	
Col 1 Vertical Force (N)	Col 2 Horizontal Distance (m)	Col 3 Torque (N·m)	Col 4 Horiz' Force (N)	Col 5 Vertical Distance (m)	Col 6 Torque (N·m)	Col 7 Net Torque (N·m)	Col 8 Time (s)
660	0	0.00	0.0	1.10	0.00	0.00	0.00
651	0.010	6.51	1.0	1.09	1.09	7.60	0.05
630	0.012	7.56	3.0	1.09	3.27	10.83	0.10
620	0.012	7.44	6.0	1.08	6.48	13.92	0.15
568	0.025	14.20	10.0	1.07	10.70	24.90	0.20
534	0.056	29.90	– 8.0	1.06	– 8.48	21.42	0.25
529	0.080	42.32	– 19.0	1.05	– 19.95	22.37	0.30
607	0.110	66.77	– 25.0	1.04	– 26.00	40.77	0.35
609	0.130	79.17	– 35.0	1.03	– 36.05	43.12	0.40
612	0.132	80.78	– 37.0	1.02	– 37.74	43.04	0.45
666	0.138	91.91	– 40.0	1.00	– 40.00	51.91	0.50
816	0.142	115.87	– 53.0	0.97	– 51.41	64.46	0.55
887	0.146	129.50	– 79.0	0.96	– 75.84	53.66	0.60
912	0.158	144.10	– 108.0	0.95	– 102.60	41.50	0.65
985	0.168	165.48	– 118.0	0.95	– 112.10	53.38	0.70
1120	0.179	200.48	– 150.0	0.97	– 145.50	54.98	0.75
1309	0.219	286.67	– 215.0	1.01	– 217.15	69.52	0.80
1547	0.240	371.28	– 274.0	1.03	– 282.22	89.06	0.85
1654	0.284	469.74	– 322.0	1.05	– 338.10	131.64	0.90
1174	0.300	352.2	– 232.0	1.07	– 248.24	103.96	0.95
630	0.308	194.04	– 100.0	1.08	– 108.00	86.04	1.00
0	0.309	0.00	0.0	1.08	0.00	0.00	1.05

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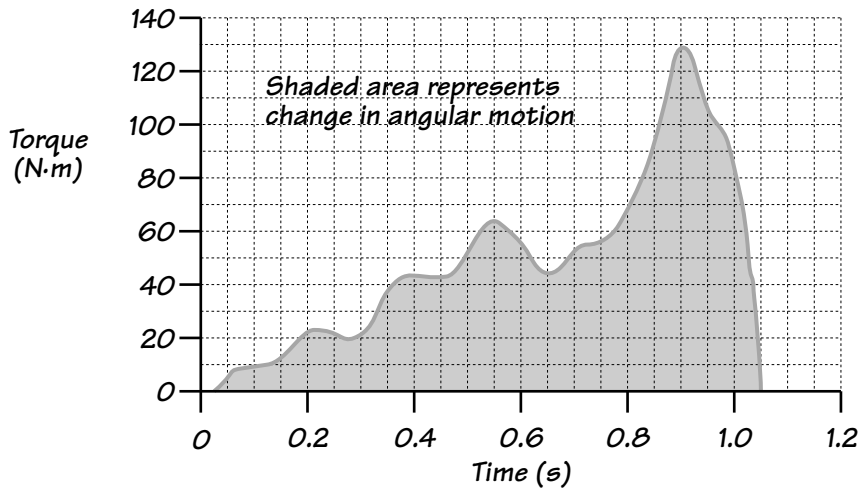
Figure S28 Graph of Torque v Time during take off phase of flic flac.



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A value for Angular Momentum derived using the square counting method is 51 $kg \cdot m^2 \cdot s^{-1}$.